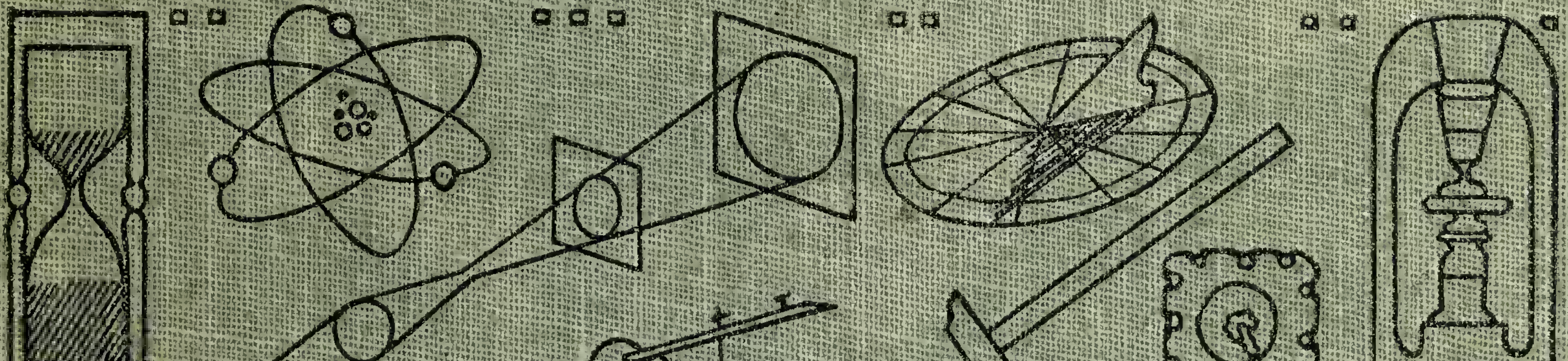


$5.00

A fascinating account of the continuing battle for scientific standards

THE STORY OF STANDARDS

by **JOHN PERRY**

Illustrated with photographs

In Brooklyn, four sizes of "feet" were legal: the United States foot, the Bushwick foot, the Williamsburg foot, and the foot of the Twenty-sixth Ward. In other American towns, beef was 27 cents a pound at one butcher shop, 33 cents down the street—but the housewife who bought at 33 cents received more meat for her money. It was like that everywhere not so long ago, but it was hard to say that anyone was cheating, for nobody was sure what weight was true, or exactly how long a foot was.

This book is a lively history of the centuries-old fight that kings, presidents, scientists, businessmen, and consumers have waged for scientific standards—to win a single "foot" that all the world would recognize. The story of their struggle is also the story of modern science, in which measurement is a fundamental tool of observation and discovery, and of modern industry, in which standards are prerequisite to systematic research and mass production.

The evolution of standards began in ancient history, when the Ptolemys, Caesar, and other rulers tried to set standards—and failed. It continued into the early years of the United States, when the framers of the Constitution tried to get Congress to set standards—and failed. Then the French Revolution produced the metric system,

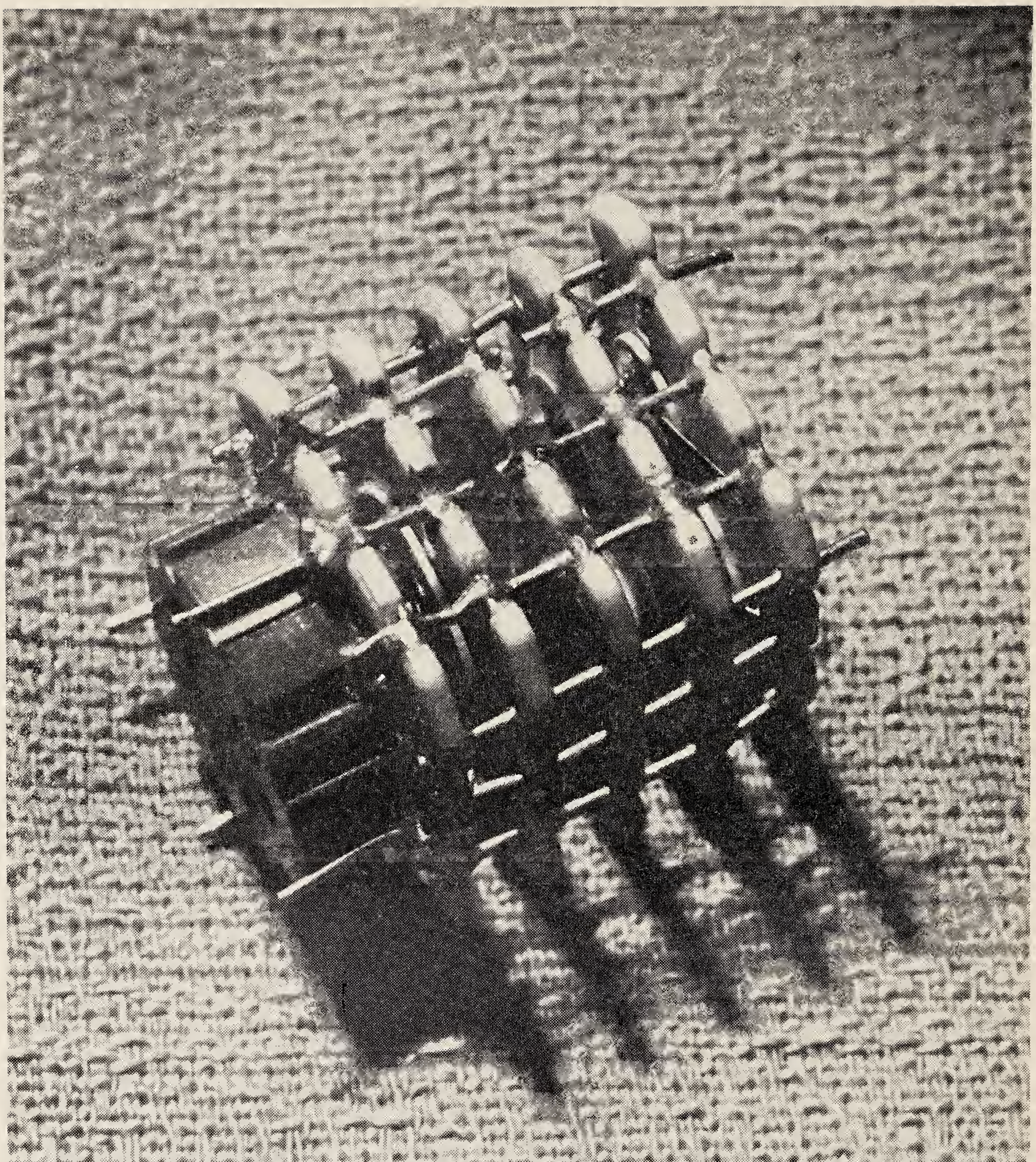
in the growth of civilization and in the taken-for-granted details of his own daily life.

Jacket design by Johannes Troyer
Jacket photograph by Warren P. Richardson, National Bureau of Standards

John Perry is a management consultant who specializes in human relations problems. Much of his work is in communications, especially the communication of information from scientists and engineers to businessmen and other laymen, and communication between branches of science. He has contributed articles to *Nation's Business*, the *New Republic*, *Harper's*, the *Harvard Business Review*, and many other magazines. He is the author of *Human Relations in Small Industry*.

Mr. Perry lives in Washington, D. C., with his wife and three children. He divides his free time between writing and family camping excursions, generally to the national forests along the Eastern seaboard.

THE STORY OF STANDARDS



JOHN PERRY

The Story of

STANDARDS

There is a measure in every thing.
—SHAKESPEARE

1955

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PREFACE

Soon after my twelfth birthday I visited Washington, D.C., for the first time. We saw the usual sights: the White House, Mount Vernon, the Tomb of the Unknown Soldier, the Smithsonian. Most impressive to me was the Lincoln Memorial; and even now, after living in Washington for sixteen years, I seldom pass it at night without pausing for a glimpse of Mr. Lincoln.

The most fascinating place on our tour was the National Bureau of Standards. That impression, too, has been a lasting one. My work has taken me to the Bureau often, and occasionally, in a corner of a hallway or office, I come across one of the exhibits which the guide showed us on that first visit.

Outwardly the Bureau hasn't changed much since then. Though there are more buildings on its uptown campus, none of them intrude on the old quadrangle. In those days the Bureau was the largest Federal scientific agency, concerned chiefly with "pure science." Our guide was full of romantic stories, such good stories that I have been careful never to find out whether they were true.

Like many pleasant happenings, the invitation to write a book about the Bureau was unexpected. When I told Dr. Astin, the Bureau director, and Reeves Tilley, chief of the office of technical information, about the possibility, they were both encouraging. More important, they offered what I hoped for: generous help, with no attempt to influence what I would write.

So it began as a book about the Bureau, but that plan soon had to be changed. I had thought I knew the Bureau well, but two weeks of reading and wandering proved the contrary. My rough outline was woefully inadequate, and the new things I discovered didn't fit into any outline I could shape.

In one building I saw men feeding tape into a giant electronic computer. In another I saw a flame burning in an altitude chamber, simulating conditions higher above the earth than man has yet risen. I saw a paper mill, pilot-plant scale, and a full-size operating glass factory. On a television screen I saw the inside of a working engine, made visible by X-rays. One towering machine produced man-made lightning. Another crushed a concrete-and-steel column.

Here and there were items being tested: shoes, a ship's plate, an airplane wing, a piece of rug, the shroud lines of a parachute, an electric meter, a lens. I opened the door of a barn-like structure and found a full-size, neat bungalow within.

"What's in those containers?" I asked a man who was unloading them from a truck.

"Human breath," he told me.

I took photographs of some men trying to burn a hole in a wall. I saw a flask of liquid helium, only a few degrees above absolute zero. And I saw a metallurgist analyze the composition of a bit of metal by clamping it in the jaws of a machine, pushing a button, and reading the data from a battery of dials.

Along the way I passed a beautifully equipped machine shop, and I learned that many of the instruments, tools, devices and gadgets in the scientific laboratories are Bureau-made. In the photographic files I saw pictures—some of which are in this book—of ingenious equipment which Bureau men had invented and built for the armed forces and other federal agencies: miniature electronic components, proximity fuzes, automatic weather stations, a new type of dentist's drill, a money-counting machine, and electronic gages to measure the thickness of metal plating without penetrating the metal. One of the latest was the NBS Physiological Monitor, to be used in hospital operating rooms, to display before the eyes of physicians and anesthetists a visual report of the blood pressure, pulse rate, and respiration of the patient.

It was all fascinating, to be sure. I could see dozens of good stories. But how did they fit together? Where was the one big story? A book about the Bureau as it is today would have a hundred chapters—but, apparently, no central theme. Searching for that theme I talked to the Bureau's senior scientists and dug into the records of the period when

the Bureau was created. There I found a plain trail which I followed back through early American history, to England in Saxon times, to early Greece and Rome and Egypt, and further back until the trail vanished in prehistoric times.

Here was the theme connecting past and present, and the book took on a new form. It is called *The Story of Standards,* but it would not be an exaggeration to call it a history of science. True, in modern times "science" has broader meaning than "standards," but standards are its foundation. Through most of history, men who sought to understand their environment were striving to provide that foundation.

When a research scientist endeavors to determine the properties of a substance, his basic tools are measuring instruments. Working with infinite patience and care, he ascertains dimensions, mass, and density. He makes delicate measurements of such qualities as expansion, compressibility, tensile strength, resilience, conductivity.

It may seem paradoxical that the instruments he uses could not be made accurate and reliable until science knew a great deal about the properties of materials. Standards of measurements are older than written history; men were making measurements before they learned to write. But scientific standards, standards of known accuracy, are comparatively new.

In the nineteenth century, for example, scientists sought understanding of the phenomenon called electricity. To discover its properties, they had first to discover how to measure them, to create new standards and units of measurement, and to invent instruments. Measurement is not merely the basic tool of science; it is one of the frontiers of science, and many great discoveries have been made on that frontier.

Measurement is not merely the concern of science, of course. From the earliest days of civilization it was essential to trade and to craftsmanship. Science has had responsibility for fixing and maintaining standards for about two hundred years. Before then, the standardizers were merchants, rulers, and priests. The first few chapters of this book tell the story of standards in those earlier times, and that story is a kind of low comedy. The testimony of witnesses who appeared before a committee of the British Parliament in 1758 is rich with unconscious humor.

In the United States, the story is full of famous names: the framers

of the Constitution, who gave Congress power to fix weights and measures; George Washington, who thought the matter important enough to discuss in his first message to the First Congress; Thomas Jefferson who, as Secretary of State, conceived a remarkable plan to provide the United States with a radically new system of measurement; John Quincy Adams who, holding the same office, wrote a report which is a classic in the science of measurement, in statesmanship, and, indeed, in literature. I was delighted to discover a man named Hassler, a Swiss immigrant who succeeded in usurping the powers of Congress and performing a task the Congress had long neglected.

Such a story is best told from a vantage point, and there is no more strategic eminence than the Bureau from which to survey science and standards in the United States. In modern times science has grown explosively, and explosions split and scatter. Science has divided into branches and specialties and subspecialties, so much so that one kind of specialist often has difficulty communicating with another.

The basic unifying force is standards, a word that has taken on successively broader meanings. As it has, the work of the National Bureau of Standards has broadened. The meter bar and kilogram still rest in the vault, still serve as fundamental standards, but there are hundreds of new standards, too. One of the new fields of measurement, for example, is called dosimetry, the measurement of potentially harmful radiation. Fixing standards and providing measuring instruments is the first step toward prescribing safe dosages, the limits of radiation to which the human body can safely be exposed—whether from an X-ray machine or a nuclear explosion.

The Bureau is the nation's central physical laboratory. More than that, it is a group of exceptionally well-qualified scientists and technicians, a resource which has frequently been called on in war and peace to perform difficult and unusual tasks. The Bureau did pioneer work in materials testing; the two-billion-dollar instrument industry had its source in Bureau laboratories; Bureau men have had a part in building most of the new industries of the twentieth century. The latter chapters of this book tell this story, a story of American science, of what has been accomplished and what lies ahead, what's happening now on some of the new frontiers.

Though told from this vantage point, this isn't a book about the

Bureau, certainly not one intended to glorify or make its contribution seem larger than the fact. The men of the Bureau wouldn't want it that way. A scientist prizes most highly the respect of his scientific colleagues; few scientists seek personal publicity, and many are wary of it. The book is deficient, I know, in giving credit to individuals, Bureau scientists of the past and present. Some are named. Many more, of no less stature, are not. I chose examples, but not by a scale of values.

Not long ago a committee of scientists and businessmen, none of them in the federal service, was asked to review and judge the Bureau's work. In their report, which was often outspoken and critical, they said:

> "The Bureau of Standards has high standing among the scientific and engineering people of our country and its superior qualities are recognized in other countries. This results from the high quality of the professional staff, their dedication to the Bureau and the integrity of their scientific and engineering work."

No one could spend several months at the Bureau, as I did, without sharing this opinion.

These few months were a warming experience. The assurance of the first discussion was more than amply fulfilled: generous help without a hint of persuasion.

Dr. Astin and several of the Bureau's distinguished senior scientists, including Dr. E. C. Crittenden, associate director emeritus, Dr. F. B. Silsbee, chief of the electricity division, and Dr. A. T. McPherson, associate director for testing, read most of the manuscript in draft; chapters were read by division chiefs. Their comments helped me to avoid many errors, and they enriched the book by contributing information I could not otherwise have found. Beyond this, there is a long list of men and women who helped, by providing facts from their own files and being quite patient with a layman who sometimes had difficulty grasping a point.

William Reeves Tilley, chief of the office of technical information, and his staff, including William K. Gautier and John R. Friedman, helped in countless ways, assembling mountains of information, arranging appointments, and checking my drafts. The color photograph

on the dust jacket is by Warren P. Richardson, the Bureau's motion-picture photographer, one of whose films recently won a high award at the International Film Festival in Italy.

For much of my stay at the Bureau, I was the guest of Miss Sarah Ann Jones, librarian, whose compilation of the Bureau's official chronology was an invaluable guide. I am indebted to her and her staff for help in using the library's excellent collection.

Two points should be made clear. First, any errors of fact are mine. The book has been revised since Bureau men read it, and I did not ask anyone to go beyond his own knowledge and files in verifying historical information.

Second, the Bureau men who read the manuscript were careful not to comment on matters of opinion. The opinions are my own; and I am sure they differ, on some points at least, from those of Bureau officials. I did not ask Dr. Astin to contribute a preface, which might have appeared to place the imprimatur of the Bureau on the book.

So we begin the story of standards. I hope the reader finds as many surprises as I did.

John Perry

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THE STORY OF STANDARDS

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TOO MANY FEET

If at times you feel man's history is a record of persistent folly, a chronicle of incorrigibility, a pathway of error rutted by incessant use—this story may refresh your faith in humankind. It may persuade you to hope for change, even if the items of mismanagement you most deplore have been chronic for centuries.

The change might come. And, as you shall see, it could come with dazzling speed, and be so sweeping and profound that within a generation the errors of the past would be forgotten.

This story concerns, in the beginning, a few innocent objects: lumps of rock or metal, bars of wood and brass, hollow vessels. The lumps might be called pounds or talents, the bars feet or cubits, the hollow vessels any of a hundred names. These objects are known as weights and measures; they are older than written history; and their innocence is deceptive. Of all man's efforts to discipline his environment and give order to his affairs, none have been as ludicrously unsuccessful as his countless "reforms" of weights and measures.

Shih Huang-Ti was a founder of the Chinese Empire, and under him was built the Great Wall against the Tartars. He had a design for Chinese unity: one law, one weight, one measure, in place of the discords and confusions of the petty states. The Great Wall stood, but not his standards of weight and measure.

Charlemagne tried it, and William the Conqueror, and Henry the Eighth, and Talleyrand. The rulers of ancient Egypt swore by Isis to

preserve the sacred cubit. Standards of weight were sealed by the priests of ancient Sumer, and by indomitable Elizabeth of England. Standards of length were built into the pyramids and into the churches of early France and England.

King, emperor, or minister—as each came to power he looked about him and found his domain abounding with debased and corrupt standards of weight and measure. This inhibited his rule, impeded trade and commerce and the collection of taxes. More, it was a challenge to his power. It seemed to require so little power—and so little wisdom—to set matters right, to promulgate standards which would command confidence and respect. So each issued decrees; but the ruler who decreed unity and order seldom accomplished more than aggravating the confusion.

"A false balance is abomination to the Lord, but a just weight is His delight," declares Proverbs 11.1, and the Bible contains many such injunctions. But in eight thousand years of history there has been much for the Lord to abominate, for balances lied and weights were false. Whatever unknown genius conceived the first weight, he was soon followed by another who conceived a dozen ways to pervert it.

A challenge to a ruler's power was always present and usually accepted: the French revolutionists began their reform of weights and measures while tumbrils rolled through the streets. George Washington called for speedy action in setting up national standards in his first message to the first Congress of the United States.

A few reforms were partially and temporarily successful. The Egyptians, Greeks, and Romans built systems of measurement which were respected through much of the civilized world. But in the Dark Ages all systems disintegrated and were forgotten. Centuries later, when William the Conqueror came to the throne of England, men had reverted to primitive, crude standards, and there was nowhere in the world a national system of good repute.

Instead, men used an incredible diversity of units, derived from unknown sources and forgotten accidents. A "foot" might equal 10 modern inches, or 13, or 17, or even 27. Half a dozen versions of the foot could be found in such a city as Rome, and a dozen other units of length with equally uncertain values. It depended on what was being measured, and where, and when, and by whom, and whether one was

buying or selling. A merchant used one measure when he bought, another—identically named—when he sold.

This is history, yet not all is ancient or medieval. In our own century, in Brooklyn, New York, there was a time when the city surveyors recognized as legal four different "feet": the United States foot, the Bushwick foot, the Williamsburg foot, and the foot of the 26th Ward. All legal, all different. Some strips of Brooklyn real estate were untaxable, because, after two surveys, made with different units, these strips, legally, didn't exist!

This record, centuries of error and confusion and deliberate subversion of systems, is the more remarkable because measurement was among man's first intellectual achievements. He learned how to measure centuries before he learned to write, and it was through measuring that he learned to count. In the list of talents which sets man apart from other animals, his ability to measure ranks among the highest.

Because he could measure, man could become a carpenter, a worker in clay and metals, an astronomer, a navigator, and a merchant. In ancient times as today, measurement was indispensable to man's inquiries into the properties of nature.

Peking and Neanderthal men had implements. A stick *so* long was right for a club or spear; a stone *so* large made a good ax or hand implement. A tool that worked well became the model and standard for another. Man was his own measure in those days. To measure a short distance he used the breadth of a finger or his palm. Longer units were his arm's length, or the span of his outstretched arms.

Since he could not count—not beyond two or perhaps three—he needed a variety of units of different sizes, and these units were separate and distinct, not related by ratios as we relate the inch, foot, and yard. Such natural units of length were common to all early tribes and to early civilizations, and they survive in the language of English measurement.

But nature played an odd trick on man. Because he had ten fingers, he learned to count in units of ten. He counted until he ran out of fingers, then made a mark on the ground and began over again. The mark meant "ten," a complete cycle. One mark and three more fingers meant ten-and-three, thirteen.

Gradually he discovered that his natural units of length, the parts of his body, could be related to each other: In the English vocabulary, the breadth of a thumb was an inch. The digit, the breadth of the middle finger, was about three-fourths of an inch. The palm, the breadth of four fingers, about 3 inches. The span, the distance covered by the spread hand, 9 inches. The foot, 12 inches. The cubit, from the elbow to the tip of the middle finger, 18 inches. The yard, measured from the center of the body to the finger tips, arm outstretched, 36 inches. The fathom, spanned by the extended arms, 72 inches.

There were other units, too, such as the finger, the hand, the nail. All had this in common: they were related to each other in multiples of 2, 3, and 4. The palm was 4 digits, or 3 inches. The yard was 3 feet, 2 cubits, or 4 spans.

Natural units of measurement were good enough for the man who worked alone. Indeed, when he made a weapon or tool or garment for himself, his own measurements, the units of his own body, were more convenient than an arbitrary system of measure would have been. When, however, men began working together, their bodily differences made difficulties. If two carpenters measured beams by their own feet or arms, two beams might be unequal in length.

The first "standards" of measurement were temporary, adopted for the duration of a task. If a group worked together, the leader set the standard, perhaps announcing that his own body would be the sole authority. It might not be convenient to use his body directly for each and every measurement; so he measured the first beam and let others be made to match. Then someone invented the measuring stick: a piece of wood, light enough to handle easily, inscribed with the units set by the leader.

This happened before the records of written history begin, so we have been able only to guess and reason how arbitrary standards came into use. But there seems not much room for doubt. As individuals, in our household activities, as when we pace off the length of a room, we still use the natural units of measure. Arbitrary units have always been needed for group and public work, and in those formative times the scale of group activity determined whether the standards were temporary and informal, or organized into a system.

The day-to-day standards of groups became the customary standards

of a tribe or a community. In such a great undertaking as the building of the pyramids there could be but one standard of measurement, a master standard embodied in some permanent physical object, from which copies could be taken for the use of every work group.

Some community standards were compromises of individuals standards, the measurements of an average man. Sometimes a ruler decreed his personal dimensions should be the standards; and he might be exceptionally large or small. But whatever the origin of a standard of length, it was likely to be fixed in some permanent physical form, an object which could be referred to in the ruler's absence or after his death.

The pyramids and other ancient structures show that their designers and builders had great skill in measurement and made use of quite precise standards, and from these structures archeologists have learned much about ancient measures. The pyramids were not only built by standards, they became permanent standards for public use.

The base of the Great Pyramid at Giza is 500 cubits long, and the Egyptian cubit used in this construction measured 18.24 modern inches. Thus the length of the base is 9,120 inches, or 760 feet, and the perimeter of the base is 3,040 feet. Here is either a coincidence or evidence that Egyptian astronomers were incredibly skilful. For 3,040 feet is just one half of 6,080 feet, which is one of the values of the meridian mile, one sixtieth of a degree of the earth's meridian.

Some authorities insist, at times vigorously, that there isn't the slightest doubt about it: the Egyptians, or some earlier people, were just that good. Jean Bailly, author of *Histoire de l'astronomie,* wrote in 1785: "The measurement of the earth was undertaken a vast number of ages ago in the times of primitive astronomy. . . . We pass contemptuously by the results of ancient astronomical observations; we substitute others and, as we perfect these, we find the same results that we had despised."

A British Army surgeon, Edward Nicholson, declared in 1912, in one of several argumentative books on weights and measures: "There is not the slightest doubt that the common cubit of ancient Egypt was deduced from the measurement of the earth . . . Modern science cannot improve much on the measurements of the meridian that were

made on the plains of Chaldea, or along the Nile, at least sixty centuries ago . . ."

It's a pleasant story, and there can be no doubt that the ancient Egyptians had skills which were later lost for a time. Their astronomers discovered the motions of the planets; they fixed the length of the year at 365 days; their mathematicians made a fair approximation of the value of π. But the cubit story is probably untrue.

A number of cubits, of different lengths, were used in Egypt, and the one used to measure the base of the Great Pyramid was oldest of all, the natural cubit of six palms, almost certainly brought from Chaldea long before.

Egyptian astronomers did attempt to measure the earth's meridian, but probably not until two thousand years after the Great Pyramid was built, and their calculations then were anything but precise. One of these astronomers, who made substantial corrections in the work of his predecessors, was Ptolemy, and he discovered that the base of the Pyramid had a neat relationship to his estimate of the meridian mile. But by Ptolemy's time a good deal of sand had accumulated around the Pyramid, which made his measurement of the base rather shorter than it should have been, 690 feet instead of 760! When more modern measurements of the base were made, however, a little calculating turned up an equally satisfactory coincidence.

In any case, the length of a meridian mile is somewhat adjustable to meet the needs of those seeking coincidences, for the earth is not round, but flattened at the poles. The length of 6,080 feet is the old British Admiralty meridian mile. It has recently been superseded, along with the United States Nautical Mile, by the International Nautical Mile of 6,076.10333 feet.

Deducing history from coincidences is entertaining, but not persuasive to mathematicians. The Pyramids have many dimensions, and by judicious selection one can discover an endless number of coincidences.

Flinders Petrie, the Egyptologist, observes that the length of the diagonal of the squared royal cubit—not the one used in measuring the base of the Great Pyramid—is almost exactly the length of a pendulum which would oscillate 100,000 times daily at the latitude of

Memphis. "The close relation seems very unlikely to be accidental," he concludes.

Well, here is a new discovery, made only this afternoon: still another cubit, measuring a little less than 21.6 inches, was used in laying some of the upper courses of the Pyramids. This dimension is almost exactly one million times the wavelength of light from a mercury 198 lamp, a lamp employing a rare isotope of mercury made by bombarding gold with neutrons! Surely one can conclude that those wonderful Egyptians were familiar with nuclear physics!

The basic coincidence in the cubit-mile relationship cannot be credited to any astronomer, however: that a meridian mile should be 4,000 times as long as a man's forearm!

Men were measuring cubits with their forearms centuries before they looked inquiringly at the heavens. Even if the improbable story were true, and the Chaldean or Egyptian astronomers had made such wonderful measurements, all that could have happened is a minor adjustment in the length of one of the many cubits then in use.

Why such diversity?

Most units of length, wherever evolved, bore names of parts of the body: foot, digit, palm. Standards were evolved first by groups, then by communities. The foot agreed upon by members of one community might differ by an inch or two from that agreed upon in the next.

In time such standards collided. A conqueror would try to enforce use of his units in a conquered area. Standards of strong tribes and nations spread. Those of weaker groups were driven out. But frequently they were driven only out of official use. Trades and crafts, accustomed to one set of units, resisted change. Through much of history, for example, workers in textiles have kept their own peculiar standards and terms.

As the driving-out process progressed, it became more difficult, for those standards that survived were strong. Indeed, some of the weakest standards have been those promulgated by rulers; the strongest those maintained, as habit and custom, by crafts and guilds.

One way of studying the spread of civilizations and empires is through study of ancient measures. Cubits can be traced from Chaldea to Egypt, through Babylon, Asia Minor, and, ultimately, to England.

But while measurement was a highly developed art at the centers

of early civilizations, the extension of standards was fraught with opportunities for error. The official, ultimate standard might be the length of a wooden beam, or the distance between two marks inscribed in stone. By much use, such standards became worn and coarse; they were subject to weathering and damage, and it was not always convenient to refer to them. Copies were made, often crudely, and distributed; and copies were made from the copies, with further errors. In a city distant from the site of the basic standard, there might be no measuring instrument which had ever been directly compared with it.

Though natural relationships among units had been found, they were often changed arbitrarily. In Athens the foot was three fifths of the cubit. In Egypt at the time of the first Ptolemy, a foot was two thirds of a cubit. In another place it might have been half a cubit. Most Chinese foot measures were longer than the modern English foot, while many of the foot measures adopted in Europe were shorter, though some foot measures in Italy were longer than an Egyptian cubit!

Despite variation, error, and corruption, the best of the ancient systems—Egyptian, Greek, and Roman—were strong, workable, respected, and accepted. They were supported and strengthened by increasing knowledge of science and mathematics, and skill in precision craftsmanship. Goldsmiths, carpenters, weavers, ceramists, shipwrights, and stonemasons made measurement an art. So it seemed that progress was being made, until those dark centuries when empires crumbled, and when much of what knowledge men had gained was discarded, suppressed, hidden, or forgotten.

In Saxon England, as throughout Europe at that time, the natural units were all men had, the parts of their bodies and such objects as grains and stones. An inch was four barleycorns. Athelstan, tenth-century Saxon king, made the barleycorn legal as a unit of weight, too. Two centuries later King David of Scotland issued an edict that would have shocked the Greeks, declaring the Scottish inch should be the average of "the thowmys of iij men, that is to say an mekill man and a man of messurabil statur and of a lytell man. The thoums are to be meassurit at the rut of the nayll."

There was a kind of official standard in Saxon times, a yard bar kept at Winchester, which King Edgar designated as the sole official

yard. But this meant less than one might think, for measurement had so degenerated that the very concept of standards had been lost. A yard, in Edgar's day, was not a unit of length; it was a measure of cloth, and in decreeing the yard bar to be official Edgar was not setting a general standard but attempting to regulate traffic in textiles. Not until the twelfth century, for example, was the yard used to measure land. Officers of King John were then equipped with iron yard bars to perform their tax-collecting duties. But whatever the King might wish, the people clung to their own ways and terms.

Even ratios varied. Four barleycorns to the inch was the Saxon standard, but Arnold's *Customs of London,* published about 1500, says that "The Lengith of a barly corne iij tymes make an ynche." The English mile was then the same as the old Roman mile: a thousand paces, supposedly 5,000 feet.

William the Conqueror took the old Saxon yard bar and had it moved to Westminster in the care of his chamberlains. Richard I appointed inspectors of weights and measures, and equipped them with iron *ulnae.* John, who signed the Magna Charta, had his iron yards. But a century later the law declared that "three barley corns, round and dry, make an inch." Some said barleycorns were anything but uniform, even if taken from the middle of the ear. But in point of fact the alleged ratios—so many corns to the inch, so many feet to the mile—were only legal fictions. No subdivided linear scales were available. Even the official yard bars were not divided into feet and inches. An inch was—an inch. There were many special units of length: the point, line, tail, tally, link, fathom, perch, pole, chain, furlong, cable-length, rod, *ulna,* medium foot, gad, quarantene, league, pace, palm, hand, and others. Each had its variants; there were perches of 10 feet and perches of 24, and others in between. Each unit was used for its own special purpose, and the sailor's fathom would never be compared with the farmer's furrow-long.

Like earlier rulers, the English kings sought to reform measurements and impose their standards throughout their realm. In 1490 Henry VII adopted a new standard, an octagonal yard bar, roughly made and crudely subdivided. A century later Elizabeth replaced his with hers in the Exchequer, a brass rod half an inch square.

Francis Baily, English metrologist, saw this rod in the archives in

1836, and commented: ". . . this curious instrument, of which it is impossible, at the present day, to speak too much in derision or contempt. A common kitchen poker, filed at the ends in the rudest manner by the most bungling workman, would make as good a standard. It has been broken asunder; and the two pieces have been dovetailed together; but so badly that the joint is nearly as loose as a pair of tongs. The date of this fracture I could not ascertain, it having occurred beyond the memory or knowledge of any of the officers at the Exchequer . . ."

Though the bar thus ridiculed was three centuries old, Mr. Baily had reason to be disturbed, for until a short time before he saw it Elizabeth's bar had been the sole official standard of England—and not only England! Copies had recently been made, and, accompanied by impressive parchment certificates, circulated through Europe, and even came to the United States. Such a bar lay in the vault of the United States Treasury, the nearest thing America had to a national standard.

Each of the American colonies had had its own standards, but the fact that most were of English ancestry did not make them identical. They had been imported at different times, in some cases quite casually by people who had not thought it important to inquire how they had been calibrated. A few had been officially compared with English standards and duly certified. Others were no more official than a schoolboy's wooden ruler. More often than not they were carelessly kept, and authorities might have had difficulty finding a few of the originals.

The settlers had not found use for all of the old English units, since some were peculiar to trades not yet established in the colonies. In common use here were the league of 3 miles, the mile of 8 furlongs, the furlong of 40 poles or perches, the pole or perch of 5½ yards, the fathom of 2 yards, the ell of 1¼ yards, the yard of 3 feet, the foot of 12 inches, and the inch divided into 10 lines or peppercorns. A few others had limited use, such as the hand for horsetraders.

When George Washington became the first President of the new American nation, he had a clear mandate from the framers of the Constitution to attempt what rulers of the past had tried. Though many powers had been reserved for the States, the Congress was given sole authority to fix weights and measures. Washington saw the need

for unity, and his first official message to the Congress urged the Members to exercise their power promptly.

What happened then is a story to be told a little later—but a clue has been mentioned: that in Brooklyn alone, in 1902, there were still four different feet, all legal!

What we take for granted today—indeed, what is so essential to every branch of industry, commerce and science—certainty and security in standards of measurement, is, in fact, little more than a generation old. After thousands of years of error, futility, corruption, confusion, change, and frustration, stability and permanence have somehow been achieved.

Out of the babel have arisen two great systems of measurement which now dominate the world, English and metric. In America we measure length in feet, while most Europeans use the meter. Yet we and they have the same fundamental standard of length: the international meter bar safeguarded in an underground vault near Paris.

We have our differences with the English, too. Though Americans and Englishmen both measure length in feet, the British have never accepted the international standard, and over the years the length of the English foot has drifted slowly and slightly away from the American. But the difference between them is known with great accuracy, so those to whom it matters can compensate for it.

Such permanence, certainty and universality were sought for thousands of years, and every effort failed. Why such a sudden change, then, in recent times? Not because rulers are more powerful, artisans more skillful, administrators less corrupt, or all of us much wiser. It was not the powers of state that brought about the transformation. Indeed, the Congress of the United States has not yet, in any comprehensive way, complied with George Washington's request.

Essentially, what happened is that measurement, once an art, became a science, and responsibility for standards passed from the hands of rulers into those of scientists.

Measurement was an art when measuring was primarily a concern of commerce and craftsmanship, when the only needs for measurement were to cut cloth, sell corn, or make the ends of two beams meet.

What most impeded the development of standards in those days

was the nature of the things that were measured, for under the best of conditions most of them could be measured only approximately. What is a bushel of corn? The measure may be filled to the brim, but if it is then vibrated the grains will shake down and compact, making room for more. What is a pound of corn? The same corn that weighs a pound on a dry day will weigh more in humid weather. Fabric stretches and shrinks; liquids expand when heated; the surveyor's chain cannot be used with precision over uneven ground. In commerce there are three variables: quality and price, as well as quantity.

Early natural philosophers sought to refine the standards of their times, but they were frustrated by errors and discrepancies which they could not explain. Two yardsticks made of different materials may agree today—but differ tomorrow. Weights are affected by temperature and barometric pressure.

Thus there could be no really accurate standards until men discovered the laws of nature—until they understood the principles of thermal expansion, for example. But of course it was not enough to know, generally, that most materials expand when heated. To correct for such variation, one must be able to measure both the expansion and the rise in temperature.

Standards and science are inseparable. The story of standards is the story of science itself. Not all science is measurement. Some of the most important discoveries were, at first, qualitative observations. But when measurement was not the first step, it was the second, and through measurement most of the laws and axioms and principles of science have been formulated.

What did Archimedes say about the lever? That *equal* weights at *equal* distances from the fulcrum are in equilibrium; that *equal* weights at *unequal* distances are not, the weight at the greater distance from the fulcrum tipping that arm of the lever down. Or his principle of equilibrium in fluids? A body immersed in a fluid is buoyed up by a *force* equal to the *weight* of fluid displaced.

With the beginning of the Renaissance, the discoveries of the Greek scientists were gradually recovered or rediscovered. In the seventeenth and eighteenth centuries, experimenters developed great skill in measuring. Yet they were handicapped, despite the excellence of their techniques and the sensitivity of their instruments, for they could not

refer to authoritative standards of equal or greater merit. There were national standards, such as Queen Elizabeth's much-abused yard bar, but they were crude, and the official copies of them far worse.

The investigators of nature needed something better than this. What they needed especially was a common language of measurement, so one experimenter could reproduce the work of another. No existing national system provided this, but in time the scientists obtained their own, from the instrument-makers. This was James Watt's calling, at the University of Glasgow. His acquaintance with the steam engine began when, as an instrument-maker, he was asked to repair a working model of the primitive water-pumping steam engine then in use.

Instrument-makers had access to such national standards as then existed, and they copied them as best they could. But the instruments they produced were far superior in workmanship, less subject to coarsening, abuse and distortion; and with the aid of scientific colleagues, they learned how to standardize them for such variables as temperature and barometric pressure. These craftsmen were the first scientific standardizers. Occasionally a government called on them for advice and help, as a committee of the British Parliament did in 1758. But the science of measurement was well developed long before any government made full use of it.

The history of scientific national standards begins with two dramatic events: a fire and a revolution. The French Revolution of the 1790's brought forth the metric system. The fire, which destroyed the Houses of Parliament in 1834, ruined the existing British standards, and in their reconstruction the imperial system of weights and measures was born.

The old concept of standards, of weights and measures, was static, custodial. According to this concept, it was necessary merely to designate certain objects as the official standards, put them in a place of safekeeping, and thereafter use the power of government to make men conform to them. Our law which established the National Bureau of Standards gave it "custody" of the official standards. But custody is a poor word; for metrology, which is the science of measurement, is a lively and vigorous science indeed, with many problems yet to be

solved. Its frontiers are the frontiers of the physical sciences. It is a young science, too, and of the leading nations of the world the United States was almost the last to give it recognition.

In the past, "measurement" meant length, mass, and time. To maintain standards, units of weight and length were placed in the vaults, while it was the sun passing overhead that provided the time standard. But in the investigation of nature, scientists have found many phenomena which cannot be measured with a foot ruler, weighed on a scale, or timed with a stopwatch. To study and understand these phenomena, new units of measurement have been devised.

A century ago a man named Faraday took a length of wire and wound it into a coil, connecting its terminals with a sensitive instrument. He plunged a bar magnet into the coil, and the needle of the instrument was deflected; when he pulled the magnet out of the coil, the needle moved briefly in the opposite direction. Here was a phenomenon fascinating to investigators in many countries, a mysterious force. They called it electricity—but what was it?

They spoke of "strong" and "weak" electric currents, but no single unit of measurement could be found to provide a scale of strength and weakness. Instead they discovered that this invisible force has several dimensions, like the flow of water in a pipe, which cannot be described adequately by mentioning only its pressure or its rate of flow or the diameter of the pipe.

One can call this research an inquiry into the basic nature of electricity. Or it can be called a study in measurement, a search for ways to measure electricity. Perhaps they are not quite the same, yet they cannot be separated. Measurement is the investigator's most essential technique; but he cannot learn *how* to measure without understanding *what* he is measuring.

One by one the dimensions were discovered and new units named: the volt, ampere, ohm, and so on. A final step remained: the fixing of standards, so that results obtained in one place could be reproduced in another.

The National Bureau of Standards is the source of more than seven hundred standards today, and more are being added each year, as science and standards move forward. Some of these are standards of measurement, units to measure luminosity, heat, temperature, viscos-

ity, radiation, and frequency. Some are standard samples of materials, basic reference points for manufacturing industry.

Because this book tells the story of standards, it is also a story of science. Most of its heroes are scientists, men such as Isaac Newton, Lord Kelvin, James Watt, Joseph Henry, and Albert Einstein—whose best-known equation linked the measurements of mass and energy.

It is also the story of the laboratories where our national standards originate, of the men in these laboratories and what they do. What they do is surprising if one has been thinking only in terms of pounds and feet. For what goes on in these laboratories is scientific research in its broadest meaning. From these laboratories came two of our most potent weapons: the proximity fuze and the guided missile. Here were built two of the first giant electronic computers. These laboratories had much to do with the development of radio, automobiles, aviation, atomic energy, and more than a dozen important new industries.

Some of the research here is fundamental, explorations at the frontiers of human knowledge. Some of it is applied research, development of an array of fascinating gimmicks, gadgets, and inventions: neon signs, a pain-easing dentist's drill, glass paper, miniature radios, blind landing systems for aircraft.

No other scientific center has had so much effect on our daily lives. In little-known ways what has happened here was essential in the design and construction of your home, its electrical and plumbing systems. The fixtures in the bathroom, the china on the dinner table, the shoes in the closet, the stockings and underwear in the bureau—all these and more have been directly and beneficially touched by the work of the men at this center of science. Indeed, if you have a piano in your home, it was tuned to a National Bureau of Standards "A."

2

THE ARTFUL CHISELERS

In March, 1907, the Women's Full-Weight Club built a roaring bonfire on the shore of Lake Michigan. This was a night of celebration. Onto the pyre they hurled hundreds of scales, wooden measures and other instruments confiscated from Chicago merchants. Joseph Grein, recently appointed city sealer, provided the fuel. He knew who had put him in office.

Not with votes; it would be another six years before Illinois women first cast ballots, and then only for presidential electors. But Chicago politicians were learning that outraged women could influence public affairs in other ways.

Outraged they were, for the offenders were the merchants from whom they bought their meat, butter, and coal. Some months before the women of the city became convinced that they were being cheated every day when they went shopping. When their first protests went unheeded, they organized. Before long the city bosses yielded, appointed Grein, gave him a clear track, and closed their ears to the surprised yelps from ward leaders.

If there were doubts as to the merits of the Full-Weight Women's case, Grein and his inspectors quickly ended them with a mass of evidence. Wary of leaks from City Hall, Grein organized his men commando-fashion. No one but he knew where they would strike next until the moment came.

One day it was coal dealers, and by nightfall more than a hundred

had been served with summonses. An inspector stopped a delivery wagon just as it was about to unload and demanded the bill of lading. It called for six tons. The inspector ordered the wagon to the nearest weighing station; the scale said four and a half tons.

Other raids brought in wholesale lots of butchers, icemen, milk dealers, candy dealers, produce merchants, grocers, fish peddlers. Several department store operators escaped prosecution by helping Grein make cases against their suppliers.

The movement had begun in New York City in 1906, when a tough Irishman, Patrick Derry, was named to head the Bureau of Weights and Measures. When he took office, he had fifteen inspectors under him, no clerks, no wagons, no money for test purchases. It seemed to be a routine appointment. Before long, however, complaints began to come into the Tammany clubhouses: This man Derry is becoming a nuisance! His men are out to break records, or something. But Mayor G. B. McClellan didn't interfere, and in twelve months Derry and his fifteen men managed to inspect more than two hundred thousand measuring instruments.

When Derry's first annual report was distributed to the press, most city editors tossed it into the wastebasket unread. But by that afternoon it was the hottest document in town. Someone noticed that the pamphlet was surprisingly thick for an annual report on weights and measures, and leafed through it. The first few pages were routine. Then came the explosive headline.

HOW THE PUBLIC IS CHEATED

In two dozen pages, Derry ripped the lid off a national scandal. As the Schenectady *Gazette* commented:

> "Generally we think of the man who deliberately overweighs things that he sells as one of the stock characters of the comic papers and the drama and novel of rural life. That we have intelligent and supposedly honest men in the commercial ranks who are indulging in this contemptible form of cheating to any marked extent is an unpleasant fact to learn, yet there seems to be no getting around the authority named."

That was the decisive quality of Derry's report; there was no getting around it. He had the statistics, the evidence, and the record of convictions. He also had something anyone could understand: a descriptive catalog, the whole bag of tricks, with photographs.

Here were yardsticks, somehow shrunken to 34 inches, and quart measures contracted to a pint and a half. Here were scales which called twelve ounces a pound.

Here was the padlock a poultry dealer slipped into each bird before weighing it. Here was the lump of putty underneath the pan of a scale, the lump of solder beneath the paper covering the pan, the milk container with the false bottom. Here were iron weights, hollowed, shaved, plugged. Here was the scale with the adjustable face, another with a bent pointer, another with a hidden string leading to a foot pedal. Here were "quart" berry boxes holding little more than a pint.

When the reporters arrived, Derry was ready for them. In his office next to the Mayor's in the old City Hall, he had the collection of horrors on exhibit and photographs to hand out.

The wire story from New York broke on front pages from coast to coast. Most newspapers followed up with shocked editorials. The more enterprising editors put men on the local story: "What's going on in our town?" A week before, the arrest and conviction of a short-weight dealer was not worth a local item; now such stories were carried by the press association wires. More scandals broke. An Albany paper accused the city corporation counsel of shielding violators. A Salem, Massachusetts, paper discovered a conspiracy to oust an "over-zealous" city sealer. Many city councils had, in recent years, turned down proposals to create bureaus of inspection; now their newspapers wanted to know why.

In Toledo, Ohio, for example, according to the Toledo *Blade*, persons who called Mayor Finch, wanting their scales tested, or making complaints, were referred to the city auditor. The auditor would tell them the city owned no apparatus to make tests. The City Council, a few months earlier, had passed a bill providing a city sealer, but Mayor Finch had vetoed it.

Ohio was the home state of the scale-making industry, and the New York *Times* brought to light a fascinating legal battle between two scale manufacturers. The first, identified by the *Times* only as "com-

pany No. 1," boldly advertised in various trade journals a remarkable scale with which, the maker claimed, a butcher could buy 20 pounds of pork loins at 9¢ per pound, sell them at the same price, and make a 3 percent profit! If the dealer's normal profit was 3 percent, the new scale would double it.

Company No. 2 then published a circular, explaining how this interesting device worked, and suggesting that no honest dealer would use it. Company No. 1 promptly persuaded the United States Circuit Court to issue an injunction forbidding distribution of such circulars! In the end, the Circuit Court of Appeals dissolved the injunction.

Derry wrote an article for *Good Housekeeping* magazine. City inspectors of weights and measures suddenly were in demand as speakers before women's clubs. "Honest weight" became a popular political slogan.

The customers were not alone in their troubles. In meetings of trade associations, retailers complained that they, too, were being cheated. The National Association of Retail Grocers, for example, appointed a Committee on Weights and Measures. At the 1906 convention of N.A.R.G., this Committee reported examples of barrels of pickles, branded 1,200 but counting under 1,000; half barrels of mackerel branded 100 pounds but weighing 89; Malaga grapes, billed to the retailer as 56 pounds but weighing only 45; and so on.

> "We might ask any retail grocer in the United States for the net weight of any package of dried or evaporated fruit, figs, dates, or actual count of pickles or fish in a barrel; net weight of vegetables and in fact any green groceries—we venture to assert there are few men in the country who could answer the question . . .
>
> "There was a time when apples were packed three bushels in a barrel; not one member of the association knows the contents of a barrel today . . .
>
> "Apparently the great question of the day with many packers is, how large can I make the package and how little can I put on the inside?"

The Committee declared that 90 percent of the members favored uniform national legislation, requiring that net contents be marked on all packages, and that falsely labeled packages be confiscated.

It was a good story and a noble cause. But the boys in the back room had learned long ago that reform movements spend themselves in time, and that reformers are often satisfied with an illusion of reform: a few arrests, a few fines, a few headlines. Neither Grein nor Derry was ever given sufficient budget to provide more than token enforcement, and even those they arrested had little to fear from the courts. The average fine was less than a good day's profit on a false scale.

Fifteen years later, in 1921, Grein and Derry had long been out of office. New York's population had grown by one and a half million, but Derry's successor had no more inspectors, and he was still pleading vainly for a thousand dollars to make test purchases. That year his inspectors made twice as many inspections as Derry's men did in 1906—and found seven times as many violations. In Chicago, fifteen years after the bonfire, prosecutions averaged only three a week; the chief inspector said that the short-weight artist could operate freely, knowing there were so few city inspectors that he could expect one to call perhaps once in ten years.

This being the case, how could any merchant afford to be honest? The butcher across the street advertised steak at 18 cents a pound, because he gave less than a pound. Who could maintain honest weight, charge 20 cents a pound, and hold his customers?

That is the insidious thing about false weight and measure. If the thieving merchant merely used his false scales to pad his profit margin, the honest dealer would have a chance. He would make a fair profit, and, in time, customers would learn that he gave fuller measure. But the trickster usually cuts prices. On any one transaction, he may make no greater profit than the honest dealer. But because he advertises lower prices, he attracts more customers.

And why not? The lesson of history seems to be that the laws were not written to be enforced; the administrators of the laws were often as corrupt as the cheating merchants; the chances of being arrested were always slight; and the penalties for being caught were trifling, not nearly as great as the penalty for being honest.

So Grein, Derry, and the Full-Weight Women were soon forgotten. Yet they joined a distinguished company of failures: Shih Huang-Ti, Charlemagne, Henry VII, Talleyrand, and George Washington, and many others who had in the past tried, without success, to regulate the

measures of commerce. They were another chapter in a long story, which began in ancient Sumer, sixty centuries ago.

Here at the head of the Persian Gulf, near the mouths of the Tigris and Euphrates, the first farmers built a civilization. They invented the wheel and worked with copper and pottery; they built boats and used metal-tipped harpoons and built temples of clay.

Long before recorded history begins, there were systems of weights and measures, primitive and local, but sufficient. Each tribe or group had its own units of weight, based, perhaps, on a designated stone, or grains of barley, or a type of shell. But in the land of Sumer, a more modern system arose. They had a system of numbers, written numerals. They had measures for grain and for land. And they had units of weight, ingots of silver, marked with the seal of the high priests and kept in the clay temples.

The art of fraud was already well established. No one knows just how or when it began, but it is not difficult to guess some of the methods. In Sumer, as in medieval England, when grains of barley or wheat or millet were the accepted units of weight, ingenious men painstakingly sorted out the larger or smaller grains of the ear, and discovered, too, that grains will absorb an impressive quantity of water.

Then as now, the economics of the situation gave the advantage to retailers in relations with their customers. What means little to the buyer can mean much to the vendor. If a butcher, for example, sets his scale so that paper wrappings are weighed in with the meat, a buyer may be overcharged no more than a cent. But if 100 pounds of paper are thus sold at the price of steak, the butcher has made a handsome profit. Indeed, if retailers were not too greedy in their false measuring, customer complaints would be scattered and faint.

It is when buyer and seller met on more equal terms that the need for mutually acceptable standards was first felt. Trade between tribes and communities brought their standards into conflict, and traders soon recognized the need for something better than locally respected bits of shell or stone, or random collections of grains.

When men met to exchange salt for copper, neither would accept the other's standards without an argument. They turned for judgment to the priests, or they attracted official attention by shedding

blood. The priest, called to serve as judge, required a standard of his own; and his scale and his weights became, within his jurisdiction, the last appeal. He could not verify every transaction. But if a trader came to him before setting out on a journey, he would verify the trader's weights, and set his seal upon them as certificate so they might be respected. Then later, on his journey, the trader could while away idle hours tampering with the sealed weights or trying his hand at counterfeiting the seal.

Perhaps some Chamber of Commerce will think these words a slur on the traditions of trade, and it will not help matters to recall that the first chambers of commerce were bands of brigands; that Hermes was the patron of both trade and banditry; that "to trade" and "to corrupt" are translations of the same Greek verb; and that the German *tauschen,* to barter, is easily confused with *täuschen,* to deceive.

But, in fairness, the past cannot be judged by modern standards, and until comparatively recent times it was well known to buyers that measurement was as variable a dimension of a transaction as price. Selling a fixed quantity at a fixed price was unheard of; buyer and seller always bargained and haggled. In the absence of accepted standards, a buyer cannot be deceived by short weight; he can only be outbargained.

In any transaction, however, measurement of quantity is as necessary a dimension as price, and although standards proclaimed as authoritative were viewed with scepticism, it was far better to have them than not, for at least they provided a common vocabulary for traders. So in ancient times, measures spread with trade throughout the known world. Sumerian weights became the basis of Chinese, Indian, and Etruscan standards. North Syrian standards have been found in points as distant as Egypt and Sweden. The earliest Egyptian weight, taken from the prehistoric Indus civilization, became in time a measure in Roman trade, appearing in the gold work of Ireland.

Standards spread by the organized or casual distribution of units of weight and length and volume, certified or alleged to be copies of recognized and respected official standards. The process of distribution was, in itself, fraught with human and natural hazards. The official standards themselves were anything but dependable.

Any physical object is subject to changes over time. Today our

official meter bar is carefully guarded against damage or deterioration. Made of the least changeable alloy known at the time, it is kept in a vault, seldom handled, and then only with maximum precautions.

Early standards were not so respected. Made of softer metal, stone, or even wood, they were exposed to weather and rough handling. Nor was the principle of a single standard understood; at times an original was lost or forgotten, while copies, crudely derived, differing among themselves, were given equal recognition as authoritative.

A Greek merchant arrived one day at a small community on the Black Sea. Since it was his first visit, he went ashore before permitting his goods to be unloaded, to learn what he could about local customs and the state of trade. The local merchants, he learned, did business in Greek units of weight, but he also learned—to his delight—that there was no set of weights in town recognized as genuine and official.

Before leaving Athens, the merchant of our story had obtained two sets of weights, each certified by the highest of authorities. He had bought his cargo by these weights, and now—

It was too good an opportunity to miss. He hastened back to his ship and spent much of the night carefully lightening one of his sets, not too much, beginning with a set of coins. The following morning, while his cargo was being unloaded, he brought this set ashore and presented it to the community. Selling his merchandise by the altered weights, he collected a fine profit. He bought some goods by them, too, but he would fill out his cargo in another place, buying by the heavier weights in his cabin.

It might seem that this process, often repeated, would lead to a gradual lightening of all standards, and that human greed and error might tend in the same direction. But there were countering influences.

Merchants who sell must also buy. He who sells by a light weight gains no advantage unless he buys by a heavier one. Greed must therefore be tempered by reason. When merchants met, and found that their weights differed, the differences would be negotiable if small; if too great, they might prove an insuperable obstacle to trade.

Even the crudest natural standard, the grain, had some settling effect. If a stamped bit of silver were certified to be of 100 grains in

value, everyone knew that it might be balanced in the scale by as few as 95 actual grains, or as many as 105. Everyone knew that some grains were heavier than others, and that all were heavier in a year of good harvest. But no one would believe that the number of grains needed to balance a coin could increase year after year, from 105 to 108 to 112 and so on.

The trade of the goldsmith was also stabilizing, for no one dealt carelessly in gold. The rich man who desired a golden goblet hired a goldsmith, and his private treasurer measured out to the goldsmith a quantity of the precious metal—which the craftsman who cared for his life was quite careful to verify at once with his own instruments. When the goldsmith delivered the finished goblet, it was weighed, and its weight had to equal the issue of gold to the last grain. In the rich man's official inventory, the weight of the goblet was recorded. Such products of the goldsmith's art were often used as secondary standards of weight. The goblet, for example, might be placed in the balance against a number of coins to test them.

Archimedes helped keep goldsmiths honest by discovering a way of detecting the adulteration of gold: his principle of equilibrium in fluids. King Hieron suspected that a crown, supposedly made of gold, was in fact composed partially of silver. Archimedes weighed, in air, masses of pure gold and pure silver equal to the weight of the crown. He then weighed the crown, the gold, and the silver, successively, in water, and was able to compute the proportions of gold and silver used in making the crown.

When a system of measurement decayed almost to the point of uselessness, as sometimes happened, the cause was as much the product of carelessness and ignorance as of deliberate corruption. Then it was time for a reform, a regeneration or a new system, and the most scheming merchant was likely to be the most enthusiastic reformer. For, if one is bent upon fraud, the most strategic situation is to be the only thief at large. It is profitless to use light weights if all others do the same.

Reform of weights and measures has always been a popular undertaking. Ward bosses might hear grumblings about the zeal of Derrys and Greins, but a candidate for office in New York or Chicago could take up the cry for honest weight without losing a single vote or

campaign contribution. The strongest and the weakest kings have urged reforms, though few reforms outlived their instigators.

In all of this time, the central problem was never a scientific one. The equal-arm balance was the first scientific instrument man invented. We know of its use in Egypt seventy centuries ago, and it may be much older than that. Anyone can reconstruct this primitive balance with a stick and three pieces of string. One string is tied to each end of the stick; the third is used to suspend it by its balancing-point. The object to be weighed is tied to one string. Weights are hung from the other until balance is restored.

It was easy to improve this device. Pans or other vessels were hung from the strings to receive the weights and the materials to be weighed. The instrument was made more sensitive by thrusting a pin through the balancing-point to serve as a pivot.

Could such a crude scale be true? Every child knows that a seesaw will balance with two passengers of unequal weight if the smaller of the two sits further from the center. Especially when pans or vessels of different shapes were hung from the ends, the initial equilibrium of the scale was no proof of its equality. But even a scale with unequal arms can be used for accurate measuring. Further, there is a simple test to expose a false scale, and this test must have been known in the early dawn of history.

Let us say a vendor is selling grain, pouring it on one pan of a scale until it balances a pile of weights in the other pan. Is the buyer suspicious? He has only to insist that grain and weights be interchanged. Then, if the arms of the scale are not equal, the very forces that first brought it into balance will now exaggerate the discrepancy.

How can the argument be settled? Very simply, and with the same scale. The weights are placed in one pan. Then, instead of wheat, sand or any material is placed in the other until the scale balances. Then the weights are removed and wheat added in their place until balance is again restored. The weights and the grain have been equated.

There have been millions of false scales, but they need not have been false, for men knew how to use them truly. The scales were crude, yet remarkably sensitive, more than sensitive enough for the needs of men until a century or two ago. It was not for lack of reliable

instruments that systems of weights decayed. The problem was the units of weight: the beqa, mina, stone, talent, shekel, kat.

Of all reforms, the most ingenious and, on the whole, most effective, was coinage. Today we think of coins as currency, but currency means only a medium of exchange that is generally acceptable. Cattle once were currency. For the far-roving trader, precious metals were more convenient than cows. It was better to carry gold and silver in his panniers than to herd cattle over mountain trails. Lumps or ingots of metal became units of value and of weight, the two being indistinguishable. They were certified, marked with an official seal.

This did not deter the avaricious. A "chiseler" was just that, one who chiseled metal from a certified ingot. Coinage evolved in a series of steps designed to foil the chiselers. The chiseler could not, at least not easily, remove metal within the area impressed by the seal, for this would mar the design. Why not cover the whole surface of the lump or ingot with seals?

A few odd shapes were tried before the coin took form: a flattened piece of metal with seals impressed on both sides. At first the edges were left raw, and chiselers became expert clippers; coin-clipping was popular in medieval England. In time the milled edge was adopted to prevent clipping.

Modern terminology reflects the common ancestory of weights and coins: the British monetary pound, the tenpenny nail. For centuries the weights of the British crown treasures were recorded in pounds, shillings, and pence.

The Greeks put coins into circulation in the eighth century B.C. Before long a new kind of corruption was invented. Coinage was made a royal monopoly, and numerous rulers succumbed to the obvious temptation. Under royal orders, and in deepest secrecy, the coiners turned to metallurgical research, seeking new alloys, ways of substituting cheap metals for some of the gold and silver content of coins. The precious metal thus "saved" was added to the royal purse.

There were other significant attempts to find a solid basis for standards. The British Parliamentary Committee of 1758 was not original in its quest for a single fundamental unit, from which all others could be derived. The Egyptians had tried it four thousand years ago.

The Egyptians' fundamental unit was the measure of length, a natural choice. From linear measure they constructed the measure of area, the foot or cubit squared. They cubed the foot, and this served as a measure of capacity. They filled a cubic foot with water, and the weight of the water was an Egyptian talent of 3,000 shekels.

This was a tremendous step forward in the art of measurement. In the past, relationships between different kinds of units were not even perceived. Area, for example, was not thought of as square measure; the unit of area was the size of a field a man could plow or plant in a day. Capacity was a handful of grain, or a vessel holding several handfuls. Length and weight were unrelated concepts.

In this sense, the ancient Egyptian system was more advanced than the system used in America today. To be sure, the mathematical relationships between our foot, acre, bushel, and pound are precisely defined, but the definitions were computed after the fact, so the relationships are accidental and awkward. For certain of their units, at least, the Egyptians began with the foot or cubit and constructed the other units on this base, in simpler ratios. To construct measures of area and capacity is a matter of simple geometry. But to define weight in terms of capacity meant that the Egyptians understood some of the properties of matter.

The talent was a cubic foot of *water*. The same measure filled with oil or sand or gold would, of course, not weigh the same. The Egyptians observed that a cubic foot of water seemed to have a constant weight.

Their theory was superior to their practice. Apparently they did not know that water expands when warmed, so that a cubic foot of warm water weighs less than a cubic foot of cold water. Further, though the concept is admirable, it is surprisingly difficult to construct an accurate cubic measure from a linear standard. With the materials and tools available to the Egyptians, it was impossible to avoid variations so large that they could be detected easily with a balance.

And the Egyptians were also unable to solve the problem which baffled the British scientists in 1758: subdividing units. This, too, is simple to state and easy to understand, but it presents great technical difficulties. Given a weight called a talent, how would one go about

manufacturing 3,000 smaller weights, identical in value, totalling one talent?

Some historians of measurement have been led astray by forgetting this problem, for when one reads in some ancient document that two units were related by a ratio such as 3,000 to 1, it is tempting to accept this as fact. But official as such ratios may have been, however impressively sealed the edicts, they were quite remote from the facts.

Over several centuries, for example, apothecaries and wine merchants, both using liquid measure, used units which were, at least in theory, a part of a single system. The apothecaries, of course, used the smaller unit, the wine merchants those of larger capacity. In the course of time, the standards of the wine merchants became degraded, while those of the apothecaries were rather well maintained. But while the actual ratios between the small and large units in use thus changed markedly, the official, theoretical ratios were unchanged.

Still, the Egyptians had a concept of measurement which was strikingly new and different, whatever their technical limitations. Measurement had begun as a tool for the craftsman and as a means of conducting trade. The farmer plowing his field had no interest in the units of measurement employed by goldsmiths, nor had the wine merchant any reason to consider the dimensions of the Great Pyramid. The concept of linking all units of measurement together in a unified system transcended mere considerations of measurement. It was the opening of a door to what was once called philosophy and what we now call science. It implied that all kinds of natural phenomena could be observed and interrelated. It offered, at least potentially, the means of scientific research, for measurement is the key to the laws of nature.

This concept was lost for almost a thousand years, and when the minds of men began once more to inquire and explore, measurement had become an almost incredible confusion. In 1850 J. H. Alexander of Baltimore attempted to compile a dictionary of the world's weights and measures, giving their equivalents in United States units. Though he identified more than four thousand items, his collection was far from complete. In hundreds of cases a once-respected national unit had become an array of provincial units which, in the absence of a binding force, had drifted further and further apart over the years.

There was the *anker,* for example, a measure of liquid capacity. In

Berlin it contained 9.07319 modern United States gallons, in Bremen 9.57413, in Hamburg 9.53683; and there were other values in Brunswick, Copenhagen, Hanover, Lippe, Lübeck, Mecklenburg and Rotterdam, the largest being 10.35988 gallons.

The *acker* was a measure of land area. But in the same province it had one value as a measure of pasture land, another if applied to cropland, a third when woodland was being measured. The Italian *braccio* was used for cloth, but its value depended on whether one measured linens, woolens, or silks, and whether the transaction was retail or wholesale, and where the transaction was being made.

Many of the variations, especially the grosser ones, were introduced deliberately by petty local rulers, who juggled measurements to gain some advantage over neighboring provinces or to further exploit their subjects. Carelessness alone could not explain what happened to the German *fass,* a grain measure, which contained almost one and one-half United States bushels in Altona, but only half a bushel at Cologne, and a quarter-bushel in Lübeck!

It was a long period of darkness, indeed. Officially, at least, in earlier times, the chiselers and clippers were pitted against the state, and the ruler's influence was stabilizing. But now power was fragmented, and greedy petty rulers knew nothing of statesmanship or responsibility.

Yet it is from this period, rather than from Egypt, Greece and Rome, that our present-day measuring system derives. Of the thousands of units identified by Alexander in 1850, the vast majority came out of this jungle, though they could all be traced to a few common ancestors in the distant past. The multiplicity of values for units such as the bushel persisted well into the nineteenth century in America.

Things are simpler and surer today. Our standards are secure and false weight is an incident rather than a custom. But we still live in the shadow of the Dark Ages. We have never been able to break away from the essential awkwardness of structure, the inconvenience of a multiplicity of units with haphazard interrelationships, which originated in those times.

3

GREAT VEXATION OF THE KING'S SUBJECTS

JOHN QUINCY ADAMS, THEN SECRETARY OF STATE, COMMENTED IN 1821 that Englishmen seemed to have had a little difficulty in managing weights and measures:

> ". . . for a series of ages they have been engaged in the pursuit of an uniform system of weights and measures. To this the wishes of their philanthropists, the hopes of their patriots, the researches of their philosophers, and the energy of their legislators, have been aiming with effort so stupendous and with perseverance so untiring that, to any person who shall examine them, it may well be a subject of astonishment to find that they are yet entangled in the pursuit at this hour, and that it may be doubted whether all their latest and greatest exertions have not hitherto tended to increase diversity instead of producing uniformity."

If Adams' elegance of phrase failed to conceal his exasperation, he could be pardoned. For the past four years he had been wrestling with what passed for weights and measures in America, a collection too incongruous to be called a system, yet—for all the absurdities—too deeply rooted to be brushed away. This was our heritage from England.

A poor heritage it seemed to Adams, an awkward, haphazard assortment of historical accidents, an assembly of units from many places

and times, brought to England by merchants and invaders, altered since by mischance, deterioration, and royal vagaries.

The Saxons had a rich variety of units, and an even richer variety of values for them. But among them was one, the mint pound, which commanded respect. Derived from the German apothecaries' pound, it has been traced back to the Ptolemaic mina. This was the pound of the moneyers, the king's private coiners, and while men might tamper freely with other standards, this one was protected by the king's wrath.

The official standard was kept at the Tower of London, so it became known as the Tower pound. It was divided into twenty shillings, each of twelve pence. But, as usual, fact and theory became confused in the structure of parts and multiples, as this "explanation" offered in 1266 shows:

> "An English penny, called a sterling, round and without clipping, shall weigh thirty-two wheat corns, from the midst of the ear, and twenty pence shall make an ounce, and twelve ounces one pound, and eight pounds do make a gallon of wine, and eight gallons of wine do make a London bushel, which is the eighth part of a quarter."

In addition to the mint pound, there was also the merchants' pound, which, generally speaking, was a fourth heavier, thus containing fifteen Tower ounces. Another pound, much used in cross-Channel trade, contained sixteen Tower ounces.

Edward III thought it was confusing to have two such similar pounds in use, so he suggested that both be discarded in favor of a third, an old French commercial pound. He was able to bring this third pound into use, but not to have the others abandoned. It is this old French pound that we use today, the pound avoirdupois. That was not its name, however. The term was first used in England to describe goods sold by weight, and, in the imaginative spelling of that day, there were many versions, from "aver-de-poys" to Henry VII's "haberdepayes." In time, it became the name of the pound.

There were other pounds, too. Raw silk was bought by an 18-ounce pound. Dyed wool was sold by a 15½-ounce pound. In the 14th century the Troy pound was brought to England from France; a few years later Henry V gave it official recognition. In England the Troy

pound contained 12 ounces, but the Scots preferred a Troy pound of 16 ounces. There were still other pounds, too, some as heavy as 27 ounces, their use limited to a single trade or area.

John Quincy Adams was particularly exasperated by abuses of language, and he cited as a horrible example the British "hundredweight"—which contained 112 pounds. Edward I was the author of this folly, which he introduced in one of the most confusing statutes of British history.

In this memorable document he referred to the "true hundredweight" of 100 pounds. He ordered this sensible arrangement to be discontinued forthwith, and a new hundredweight of 112 pounds adopted. Just to make the transition easier, he also ordered that a temporary hundredweight of 108 pounds be used for a while. Thus, five centuries ago, originated the British long ton of 2,240 pounds. The long ton is still widely used in ocean shipping. For many years coal dealers in England and America bought by the long ton, though, for some reason, they found it more convenient to sell by the short ton of 2,000 pounds!

Edward was only one of the kings who sought reform of weights and measures by decree. In 1066, William the Conqueror, on taking the throne, approved in principle what his Saxon predecessors had done, but he ordered that uniform sets of weights and measures be stamped and certified and used everywhere. Later kings also ordered that sets of standards be provided; they appointed inspectors; they had "King's Beams" set up at seaports to weigh heavy cargo. But their efforts somehow failed to achieve uniformity in practice, as Edward III complained in 1353: "Some merchants buy avoir-de-pois, Wolls, and other Merchandize by one Weight, and sell by another, and also make deceitful draughts upon the Weight, and also use false Measures and Yards, in great Deceit of us, and of all the Commons, and of lawful Merchants."

In 1423 Henry VI also observed "great Deceit" in the marketing of grain, wine, eels, and cheese. Henry VII noted that matters had not improved noticeably, "to the great Vexation of the King's Subjects."

Henry VIII said that meat had become so expensive that the poor could not purchase their sustenance, and he decreed that "every Pound of the Carcass of Beef or Pork be sold not above the Price of

one Halfpenny" and that butchers equip themselves with scales and begin selling meat by weight. But the butchers had a lobby at court, which seems to have been persuasive. Henry VIII revoked his statute, explaining that he did so "upon Petition of the Butchers, setting forth, that if they were compelled to sell Flesh by Weight, they should be utterly undone forever."

Charles I, in 1640, became aware that the "great Deceit" had not diminished, and he, too, ordered that everybody use the same weights. His successor sadly admitted that there was still "great Oppression of the People, contrary to the Great Charter, and other good laws." Queen Anne was upset by the large number of lawsuits over transactions by weight, and by wide-spread fraud in the sale of coal. And so it went through the years, with no apparent improvement, despite what Mr. Adams gallantly referred to as stupendous efforts and untiring perseverance.

In 1707, the Act for the Union of Great Britain provided that English units be adopted throughout the United Kingdom. They were not, of course, and to the splendid array of such British units as the drachm, fother, fotmal, charre, sack, clove, chaldron, butt, pipe, puncheon, firkin, stake, tun, tierce, dolium, and summa, were added an equally impressive array of Scotch and Irish terms.

In 1758 Parliament appointed a Select Committee to find out just what had been the matter for the past four centuries. The Committee's report—copies of which can be seen in several American libraries—could be studied profitably by modern Congressional Committees, as a model of scholarly research, candid but restrained presentation, and literary excellence.

One of the difficulties of the past, the Committee found, had been close to the throne. The kings' own officers and purveyors had been conspirators in the "great Deceit," practicing fraud, destroying official weights and replacing them with false units. The Committee found it a "Matter deserving Attention" that, for 415 years, though the Statute Book abounded with Acts of Parliament, the statutes were ineffectual and the laws were disobeyed. In addition to official fraud and lax enforcement, the Committee found that copies of official standards were so crude as to be useless. Further, "each new Law gave room for

some Exception, which being a Departure from the Principle of Uniformity, was a Precedent for another."

The Committee heard some interesting testimony. One day the witness was a Mr. Harris from the Mint. Mr. Harris admitted that the Mint had a pile of weights, lying about somewhere, which were called "standards," but no one ever used them. Once, out of curiosity, he had inspected them and found them quite inconsistent with the Mint's practices. The Mint, said Mr. Harris, purchased its weights from their favorite supplier, Mr. Freeman, and in the past 22 years he had never heard any complaints.

The Committee decided it was high time to do something, so, in consultation with the Royal Academy, it made a review of all existing physical standards. One yard-bar was chosen to be the sole official standard of length, and three Troy pounds were selected as fundamental standards. The Committee recommended that these be sealed and safely preserved. It recommended that measures of capacity be expressed in cubic inches, that the commercial pound bear a fixed relationship to the Troy pound, that makers of weights and scales be licensed—and that they be severely punished for fraud.

The Committee gave frank and official recognition to a problem of long standing—one that sounds strange today. Designation of an official yard suggests that there would be, almost automatically, equally reliable standards for the foot and inch, and for the furlong and mile; that an official pound would be accompanied by equally reliable specimens of the ounce and grain, and the hundredweight.

But this was, in fact, not the case. The Committee reported that it had hoped to have such parts and multiples prepared—but found this to be technically impossible, with existing instruments and methods. Parts and multiples could be made, but not with sufficient accuracy to permit their recognition as standards.

The Committee confessed its failure to solve another classic problem: finding a standard in some fact of nature. Physical standards of length and weight, if made by man, would necessarily be arbitrary; and however carefully they might be safeguarded there was always some risk of damage or loss. True, copies could be made, but to give several objects the designation "fundamental" would invite confusion;

however skillfully they were made, there would be differences between them.

True permanence, the Committee reported, required reproducibility, and this could be realized only if men could find in nature some unvarying dimension, to which they could resort if a fundamental physical standard were lost. But the Committee's advisors could find no such natural fact, and they offered no alternative to the traditional plan: arbitrary man-made standards, physical objects kept as safe as possible. Nor could they develop a practical way of basing the entire system of weights and measures on a single standard, from which all others would be derived.

Half a century passed, and then Parliament appointed another Select Committee to find out why Parliament had done nothing to put into effect the recommendations of the Committee of 1758. This new group discovered that a second committee had been formed in 1790, apparently for the same purpose, but the records of its deliberations, if any, had been lost. The third committee could think of no significant improvements to make in what the first recommended.

Still a fourth committee, convening in 1835, conducted extensive hearings, illuminating the progress made in the fifth century of the English system. There was, for example, the testimony of Mr. Thomas Pynder, engaged in the sale of lime:

> "We sold by a nominal measure, called a hundred, which was originally supposed to be 100 pecks; but it was in point of fact reduced to the cubic yard, and the lime was measured from the vendor to the customer in the cubic yard, a yard of 3 feet wide and 3 feet high, and 3 feet 1 inch the other way in order that there might be no question as to the quantity of the measure."

But a buyer of lime, Mr. James Howlin, contradicted Mr. Pynder. He explained to the bewildered Members that lime was sold by the barrel, except that in the Irish county of Wexford it was not really a barrel but a large cart rolled up to the kiln, and that a cart-full was called a barrel.

Question: What is the definition of a barrel?

Howlin: It varies. Lime is sometimes sold by the barrel of four heap bushels.

Question: Is it the Winchester or the Imperial bushel?

Howlin: It varies. I suppose it was originally the Winchester bushel. Some people who wish to get more custom make it larger.

Just before, Parliament had adopted a new Weights and Measures Act, which, apparently, was drafted by men who thought it best to take a fresh approach, rather than clutter their thinking with the ideas and experiences of the past. One of the reforms provided in this act was that stricken measure—a measure made level by striking off the heap—be used for all goods sold by volume.

Mr. Lewis Sleight, Clerk to the Commissioners of Brighton, now came forward as a witness to declare that this provision was laughed at by the public.

"Suppose a cabbage the size of my hat. How could we strike a bushel of them?"

Another witness told the Committee that it was customary for the manufacturers of weights and measures to make contracts with shopkeepers, whereby they agreed to keep their weights and scales true, for a fee of so much a year. They had found it economical to make the weights too heavy at the outset, so they would "last out the year without having the trouble of adjusting them." Such tampering with standards, for such eminently practical reasons, was not unusual. The chains used by land surveyors, for example, were usually made an inch or two overlong "to allow for the roughness of the ground."

The Committee proposed that all bottles be stamped with their capacities. The bottlers quickly protested that this was unfair, unreasonable, and unnecessary. It was technically impossible for manufacturers to produce bottles in standard sizes. And, anyway, they always tested their bottles, and those that held less than the advertised amount were used only in the export trade!

When another reform movement took shape in 1867, a national organization of merchants was mobilized to object. It was outrageous that they should be prosecuted! Who tested their weights? Local inspectors. Well, in many cases the test weights used by these inspectors had not been verified for more than forty years! There was merit in their argument, and they went on to blast open a national scandal. Though Parliament had provided inspectors, the inspectors had no

responsibility to the national government. They were hired locally, and paid out of town and county funds, theoretically; in practice many towns and counties paid them no salaries, but gave them a percentage of fines collected from shopkeepers they brought into court.

Defenders of this system argued that salaried inspectors might accept bribes from dishonest merchants. But testimony made it appallingly plain that inspectors on a commission basis were practicing another kind of extortion, in perfect safety, and with the aid of the courts. An inspector would walk into a shop, make a pretense of inspecting weights, and confiscate them. When the merchant appeared in court, his weights were produced in evidence against him. Some inspectors took advantage of the intervening time to tamper with the weights.

There were 1,375 inspectors in the United Kingdom. But Parliament had neglected, in all of its legislating, to provide standard methods of inspecting, or to define legal tolerances. Just what was an illegally light weight? Was the permissible variation one-half ounce, as some inspectors held, one-tenth ounce, or none? Some inspectors made their decisions by the turn of the scale's beam; if it turned toward the test weight, the shopkeeper's weight was declared fraudulent.

The fact is that even today, with the best of modern standards and instruments, some tolerance must be allowed. Testing in a shop cannot be as precise as testing in a laboratory. Weighing instruments carried about by an inspector are necessarily cruder than laboratory instruments. There probably was wide-spread fraud among merchants in England. But the standards of the time were so faulty, the working standards of the inspectors so crude and inconsistent, and the training of inspectors so inadequate, that even an honest merchant could never be sure his weights were true; and even if they were true he was not immune to prosecution, for an inspector's weights might be false, intentionally or by chance.

There had been complaints, of course. The Committee reproduced in its report, without special comment, a collection of letters addressed to the British superintendent of weights and measures. There were letters from consumers, complaining that they were being defrauded. There were letters from shopkeepers, complaining that inspectors were prosecuting them unfairly. And there were letters from locally

appointed inspectors asking for guidance in the performance of their duties. The superintendent had replied to all in the most correct bureaucratic fashion: the enforcement of the law was a local matter, with respect to which he had no information whatever.

The inspectors, by now, had their own national organization, and when it was their turn to testify they had pointed comments to offer. The law had not given them unlimited authority or jurisdiction. Far from it! They observed. every day, thousands of frauds which they were utterly unable to prosecute.

The law, for example, provided penalties for the use of false weights, but none for the use of false scales! They could not act on the spot; but, in each case, an inspector observing a violation had to obtain a warrant and serve it upon the violator. Street peddlers and hucksters were thus able to laugh at the law; while the inspector went in search of a warrant, the huckster moved on to another location.

As the inspectors described a whole catalog of tricks and sharp practices which, they said, were common, it was difficult to understand how there could be any successful prosecutions. The law had many defects, indeed. One inspector, for example, said there were three large weighbridges in his district, which he had inspected and found to be false. But what could he do about it? "It might not be quite convenient to confiscate a weighbridge," he said.

Other evidence disclosed that numerous towns and counties had appointed as inspectors the very men who were dealers in scales and weights. In a way this was logical, for who could be better qualified? But it had led to another type of petty extortion: in his role as inspector, a man would reject a shopkeeper's weights; then, stepping into his role as supplier, he would adjust them, for a price; both transactions taking place in the same establishment.

Innumerable ways had been found to circumvent the law. There was, for example, the device of the shrinking container, a bit of knavery which became popular in the United States in later years. The dairy trade had been selling milk in containers of certain sizes, popularly known as "penny" and "halfpenny" bottles. The sizes of these containers had been gradually and imperceptibly reduced—an

achievement apparently within the technical competence of the bottle-makers—without the formality of public announcement. The containers were still advertised as "penny" and "halfpenny" sizes, so there was really no actual lying.

Bitter was the testimony on what had happened to the Englishman's pint of beer. When he entered a pub, he called for his pint, as he always had, but what he got was something else again.

Spokesmen for the publicans agreed that it was a delicate situation, but they were, after all, merely the innocent victims of custom and circumstance. The customer, they explained, had no word in his vocabulary other than "pint," and he did not, really, mean a pint, in the literal sense, but a pint in a manner of speaking. No one, they complained, ever asked for a glass of ale, or a mug, or a pennyworth. It was always a "pint."

No respectable publican, they would have the Committee believe, ever used the word "pint," nor did one ever make representations, verbally, as to the capacities of the drinking vessels in which he dispensed beer and ale. On the contrary, his drinking vessels were on display, for all to see. The buyer knew in advance what he was getting. They did not warrant that these vessels contained pints. How could they? The makers of mugs and glasses did not certify their capacities, so a publican had no way of knowing. It was most unjust, they protested, for inspectors to come roaring into their places of business and smash all their crockery.

So the Committee deliberated, and made its recommendations, and its report, factual, candid, and restrained, was duly placed before the Members of Parliament for their consideration. And, in time, the laws were amended, and amended again, and yet again.

It happened a long time ago, of course. Looking backward, it was not difficult for able committeemen to perceive the follies of the kings—Athelstan, Edgar, John, Edward, the Henrys, Elizabeth, and others—or to see how Parliament had failed to set things right, either by failing to act, or by acting wrongly. There was no denying that the "great Deceit of all the Commons, and of lawful Merchants" was still being practiced, but it always seemed that, this time, matters could be put right.

But 1925 was not quite so long ago, and in that year the principal witness before another committee was Mr. George B. Cole, representing the Incorporated Society of Inspectors of Weights and Measures. Mr. Cole declared that selling by short weight and measure was a practice still common throughout the United Kingdom. His inspectors were powerless to protect the public. For most of the frauds they observed, the laws of England provided no penalties.

4

ART INTO SCIENCE

There was never solid ground under the reformers' feet, though it always seemed one more step would reach it. The problem was the more baffling because it appeared to be so simple.

If a man were cast up naked on a deserted island, and became convinced that his stay would be long, he would shortly invent a measure of length, and if his skills increased and broadened he would invent weights. He would fix his own standards, and he could use them as accurately as his skills permitted.

Why should it ever be more difficult than that? Let the King set the standard. Let his officers enforce it. With but a single true and certified measure for the kingdom, why should any buyer be willing to trade in unofficial units whose value is indeterminate?

Yet, in practice, it was difficult for a merchant to be honest. He might own the finest scales and procure a set of polished weights from the best maker. But the next inspector to visit him might condemn both scales and weights, if only because the inspector's instruments were faulty.

Then too, if he tried to be both honest and scrupulous—well, his customers would never allow it. On his true scale, with a pound weight in one pan, it would take just a pound of rice to bring the beam into balance. But few customers would accept this as a pound. As long as the balance has been used, customers have insisted that the beam turn in their favor. So, if he purchased a hundred-pound

sack of rice, by weighing in this manner he might empty the sack by selling only ninety-eight pounds.

It was a pleasant custom, this show of generosity, the merchants' willingness to give good measure. The lime burner had his oversized cubic yard, to attract more custom. The baker had his baker's dozen. There was always a little more than a pound of rice, or an extra pat of butter, or a free soup bone or some greens. An economist would say it all came out to the same thing in the end, for the merchant who knows that a hundred pounds purchased will yield only ninety-eight sold prices his pounds accordingly. Even so, it was pleasant, but it made people's ideas of measurement somewhat vague.

This vagueness persists in the modern American kitchen where, for all the showy efficiency and gadgetry, measurement is still little better than in medieval England. Home economists have preached "level measure" for almost a generation. Most cookbooks have adopted level measure as standard. But despite the earnest efforts of home economists and the makers of baking powder, millions of cooks cannot resist the generous gesture. To the despair of recipe writers, they are incorrigibly inconsistent. Their liquid measurements are level, of course. They are willing to make their cup measurements level. But dry measurements with a spoon are more often heaped or rounded.

It would be difficult for a cook to measure accurately even if she wished. A quarter-century ago, the executive secretary of the American Home Economics Association complained bitterly that it was almost impossible to find an accurate one-cup measure for the home. More recently the Association made another survey of the situation, buying and testing hundreds of kitchen measuring implements—and found three fourths of them to be grossly inaccurate.

On this the law is silent. Kitchen measuring tools are not used in buying and selling, so their manufacturers can do as they please. But, since modern industrial production machinery can make an accurate measure as easily as an inaccurate one, it is interesting to speculate as to the reasons why so many have chosen to exercise their license.

A few manufacturers of teaspoon measures appear to have undertaken an unannounced reform, conspiring against the housewife to frustrate her mistaken generosity. The teaspoon measures they sell are as much as forty percent undersize. Thus when a cook uses one to

measure baking powder, by rounding the measure she obtains, inadvertently, the rough equivalent of one teaspoon in level measure, which is what her recipe specifies!

This is an old question: to heap or to strike? It plagued the British Parliament for centuries. It seemed crystal-clear that level measure was the only hope. There could be nothing scientific in heaped measure. Flour can be heaped higher than sugar, and sugar higher than dry beans. Heaps can be made higher on damp days than on dry days.

Further, the size of the heap has no relationship to the volume of the container. Consider, for example, a cylinder which contains a bushel. Imagine that the cylinder is amputated, its top half cut away. Now it holds half a bushel. But if heaped measure is used, the heaps will be the same in either case, for the size of the heap is related to the area of its base. By this kind of measure, two half-bushels are greater than one bushel.

Merchants who sold by heaped measure were aware of this, of course, and they knew ways of protecting themselves. A tall, narrow bushel measure would support a smaller heap than a broad, shallow measure. They also adopted the expedient of the teaspoon reformers: false measures, so reduced in capacity that by heaping them one approximated true measures. This, said Parliamentary committees on several occasions, had gone on long enough. There was only one sensible thing to do: enforce the use of stricken (level) measure in trade.

Seldom has a piece of legislation been received with less enthusiasm. British housewives called it sheer robbery. Strike indeed! That could only mean getting less for their money. Shopkeepers were told they'd best not try any such foolishness, no matter what some silly men in Parliament said. What kind of a law was that? And who was going to summon a shopkeeper into court and punish him for giving too much to his customers? Furthermore, the whole thing was plainly ridiculous! How would one strike bushels of coal, apples, or potatoes?

So that was that. It was too bad, for the idea had seemed so appealing. Selling by weight was in such disrepute that sale by level measure looked like a possible reform.

But now, it seemed, there were a great many facts which hadn't been considered. Even with level measure, and even with containers

certified for accuracy, there is room for considerable variation. Suppose, for example, that rice is poured into a cylinder and the measure stricken, leveled off. Now if one vibrates the cylinder, the grains shake down together, and one can add considerably more rice to bring the measure up to the brim. A bushel of small apples weighs more than a bushel of large apples. A cubic foot of pulverized coal weighs more than a cubic foot of lump coal. Flour passed through a sifter increases in bulk. The shopkeeper soon learned that it was good business to measure with a light hand.

Well, then, perhaps dry measure is not so very accurate or reliable after all, and the best answer is weight. This point of view has prevailed now for some years. The housewife today seldom buys by the peck or bushel; most fruits and vegetables, and all grains and cereals, once sold at retail by dry measure, are now sold by weight.

This is an improvement, but it is not without difficulties and peculiarities. The best quality of lime, for example, is the driest; a cubic foot of the best lime weighs less than a cubic foot of poor lime. Flour—and many other commodities—are hygroscopic; they capture moisture from humid air. Modern flour mills attempt to control the humidity in their plants, and thus in their products. But some years ago, when flour was sold in bulk, the housewife who did her buying after a damp spell was charged for several ounces of moisture. All vegetables have a high moisture content; in some cases more than nine tenths of their weight is water. Exposed to dry air in a vegetable market, they lose weight, and the profits of the shopkeeper shrink. In a well-run market, vegetables are sprayed from time to time. This keeps them fresh and attractive, as the housewife wants them. It also maintains their weight.

For that matter, there are transactions in which neither weight nor volume is a meaningful measure. Years ago a Parliamentary committee heard testimony from a maker of bottled sauces, who told them the attempt to regulate was nonsense. "After all," he snorted, "I can always add more water."

Measures of weight and capacity originated as instruments of commerce, and through most of man's history they have been dealt with as such. The science of measurement, metrology, began as an

inquiry, a question posed by philosophers: What is measurement? What is weight, for example?

The word "weight" is often used loosely, even by people who know better; it is used loosely in this book. In commercial affairs it hardly matters today, though it would become important to merchants if they should begin trading with customers on Mars. But to have precise standards for use in weighing, to answer the question "What is weight?," men had to discover the difference between *weight* and *mass*.

Thanks to science-fiction stories about interplanetary travel, the difference between the two is easier to grasp than it was a few years ago. Today every schoolboy knows he would weigh less on the moon than he does on earth, and that in free flight through space he would be weightless.

Weight is not an inherent property of matter. It is the measure of attraction between two objects, such as you and the earth. This gravitational attraction diminishes with distance. If you weigh 200 pounds at sea level, you would weigh only 199.8 pounds at an altitude of ten thousand feet.

If you were weighed at sea-level, with a 200-pound block in the other pan of the scale, and then again at 10,000 feet, the same block would bring the scale into balance. You and the block have been moved the same distance away from the earth's center, so both weights have decreased. What the scale demonstrates is that your *mass* is equal to the *mass* of the block. Mass is an inherent quality. Your mass remains the same, wherever you happen to be.

One reason that *weight* and *mass* are often confused is that both are measured in the same units of pounds and ounces. Another is that two common types of weighing instruments, the balance and the spring scale, actually perform quite different operations.

When you step onto one pan of a balance and a block is placed in the other pan, the balance compares your mass with that of the block; if equal, they would be equal wherever you both happened to be.

But suppose you step on a spring scale, such as an ordinary bathroom scale, at sea level, and the dial shows 200 pounds. If the scale is accurate and finely enough divided, it would register only 199.8

pounds at an altitude of ten thousand feet. For a spring scale does not compare masses. It measures the attraction between two objects, you and the earth. The force of gravity compresses the spring. When the distance between you and the earth is increased, gravitational attraction decreases, and the spring is not compressed as much. A balance can be used accurately anywhere on earth. But if a spring scale is calibrated at the factory, it will give slightly different readings at different altitudes.

If you understand that there is a difference between mass and weight, it isn't important to stop and think which you mean before you make a statement. Few people do. Indeed, the British Parliament didn't. The official national standard of Britain is described legally as a "one pound weight," but it weighs one pound only at one fixed distance from the earth's center. It is considered and used as a one-pound mass, despite the law.

We have no national standards of weight. We do have a national standard of mass. Technically, an object which is usually called a weight should be called a mass. But it's quite customary to speak of "weights and measures," and we'll continue to do so in this book.

The discovery of the difference between weight and mass was one of the most fundamental in man's inquiry into the nature of the world around him. In the science of measurement, another important discovery was the buoyant effect of air.

Archimedes observed that an object immersed in a liquid is buoyed up by a force equal to the weight of liquid it displaces. You can demonstrate this by filling to the point of overflow a pail fitted with a spout, placing beneath the spout a vessel to catch the overflowing liquid. Now you set a pan afloat on the surface of the liquid. A small amount of liquid flows from the spout, and this you discard. Now you place a block of metal in the pan, which sinks deeper into the liquid, causing more to overflow. With a balance, you will find the weight of the block equal to the weight of the liquid that flowed from the spout.

As a ship is loaded with cargo, it sinks deeper into the water. As it sinks, it displaces more water, equal in weight to that of the cargo loaded.

A block of wood floats in water. But a block of iron will sink. This means that wood has a lesser *density* than water (weighs less per cubic inch), and iron has a greater density. But a block of iron will float in mercury. Iron has a lesser density than mercury.

The same buoyant effect occurs in air: an object is buoyed up by the weight of air it displaces. Few substances have lesser densities than air, so few will float in it. But some will. Balloons filled with hydrogen or helium will float. Indeed, the densities of these gases are so low that they will support aircraft, such as blimps and zeppelins.

Thus, while the equal-arm balance, older than written history, is a sensitive instrument, its use was complicated by phenomena which, even if observed, were not understood. Many of the phenomena were observed. The great moments of scientific history occurred when someone perceived how they could be described in principles or laws.

Anyone could see that a bit of wood floated in water, but a rock sank. Archimedes stated the principle explaining this behavior.

Weighing is, of course, generally done in air. Suppose a block of lead is placed in one pan of a balance, a block of wood in the other, and the beam comes to rest at mid-point. Apparently the two blocks are of equal weight. But are they? In fact, the wood, displacing a larger volume of air, is buoyed up by a greater force than the lead; hence it is, in reality, slightly heavier, and in a vacuum the pan holding the wood would swing down.

Is the buoyant effect always the same? Not at all! As barometric pressure rises and falls, the weight of a given volume or air increases and decreases. Then too, most substances expand when warmed, each in its own way. A ship leaving a northern port will sink deeper into the water as it moves into tropical waters. Since a cubic foot of warm water has less mass than a cubic foot of cold water, a larger volume must be displaced to buoy the ship.

The more discoveries were made, the greater became the apparent complications of accurate measurements of weight and mass. Some of the problems were mechanical, matters of workmanship, and these could cause puzzling distortions. For example, in certain experiments it is necessary to weigh an object first in water, then in air. Some of the early weights were made with handles, and water might seep in

around the base of a handle, temporarily increasing its total weight and mass.

There were fewer initial complications in perfecting standards of length. Aside from tampering and unskillful workmanship, the chief problem was thermal expansion.

Suppose that a brass bar has been chosen as the official standard of length. It is carefully constructed and kept safe in the archives. To prevent damage and wear, several copies are made, which have been carefully compared with the standard, and these are used for daily reference standards.

The length of both the master and the reference bars is affected by heat and cold. In a warm room, a metal bar is slightly longer than in a cold room. It is thermal expansion that causes mercury to rise in the tube of a thermometer. A little space is left between the end of railroad rails to allow for thermal expansion, but in extreme heat this space may be insufficient and the rails push together and buckle.

No two metals are quite alike in their tendencies to expand. Brass, for example, expands more than steel. If two measuring instruments are made of different metals, they will be identical in length at only one point on the temperature scale. Suppose that the fundamental standard of length is made of one alloy and a working standard of another, and they are identical when compared at 65 degrees Fahrenheit. Then, on a summer day, when the temperature is 80 degrees the working standard is used to calibrate a surveyor's tape. What is the relationship between the tape and the fundamental standard?

This problem was the source of an error which marred the first serious attempt to compare French and English measure. French and British scientists had been experiencing difficulty in interchange of information, for lack of common standards. In the eighteenth century the British Royal Society and the French Royal Academy of Sciences proposed to remedy the situation, and they began by having a well-known instrument-maker, George Graham, prepare two yard bars, based on the standard at the Tower of London.

These were sent to Paris, where they were compared with the French standards, and one was returned, inscribed with the French standard of length, the half-toise.

It was several years before the scientists learned that their efforts had not been wholly successful. Graham's bars were of brass. The French standard was made of iron. And the French had made their comparisons at a different temperature than had the English!

Another problem clouded this undertaking. What was the official English yard, the Tower yard or the Elizabethan bar kept at the Exchequer? Graham compared them, using a bar of his own as the intermediary, and found the Tower yard to be somewhat the longer.

The Parliamentary Committee of 1758 undertook the job of setting up a reliable Imperial system of weight and measure. Under the Committee's direction, using the best available instruments and methods, a new yard bar and a new Troy pound were constructed. These the Committee offered to Parliament, urging that they be given official recognition, superseding all others. Seventy years later Parliament acted, accepting the "new" yard and pound, proclaiming them to be the only "original and genuine" standards.

Even after such long deliberation, no one thought to include in the Act provision for guarding the standards. They remained where they had been for seventy years, with the Clerk of the House of Commons. They were there in 1834 when they and the Houses of Parliament were destroyed by fire.

It was just as well, for much had happened in science since 1758. The committee appointed by Parliament to reconstruct the standards had new resources to use. For the first time English standards could be set on a foundation of scientific knowledge.

The Act of Parliament which made the standards official directed how they should be restored. Those who drafted it had been told science could answer, at last, the classic problem of reproducibility. An unvarying natural fact had been found.

Galileo had observed that the period of oscillation of a pendulum is governed by its length. It had been calculated that a pendulum beating seconds at the latitude of London would be 39.1393 inches long. So the law directed: if the standard of length is lost, make a pendulum which will beat seconds, and from its length you can restore the British yard. From this yard, the pound can be restored. One cubic inch of water, weighed against brass weights, at 62 degrees Fahren-

heit, with the barometer at 30 inches, would equal 252.458 grains, said the law. A Troy pound consists of 5,760 grains.

The scientists summoned to perform the task found two objections to all this. First of all, they declared, the calculations were wrong. But even if they could be corrected, the lost standards could not be reproduced in this manner with sufficient accuracy. Both in the construction and use of a pendulum, and in measurements of a cubic inch of water, errors of observation and errors caused by insurmountable technical difficulties would be too great. Successive experiments yielded such varying results that no reliable finding could be made.

So, despite the law, the scientists adopted other methods. To reconstruct the yard, they collected a number of secondary standards, yard bars known to have been compared directly with the lost one. Oddly enough, this promised to yield a better standard than the original, which had been much abused before its loss. The old method of making comparisons made use of a beam compass fitted with fine points. The lost bar had been thus used so many times that compass points had worn away the edges of the fine markings, so that the original centers could no longer be determined.

Now a better method was available: micrometer microscopes. Adopting this method, the scientists prepared to make the most precise measuring apparatus ever known on earth.

Tons of masonry were massed for its foundations. Piers and transoms of stone were erected on this vibration-free foundation to carry the comparison microscopes. On the foundation rested a large carriage, which bore a trough of water, within which there was placed a trough of mercury, and the bars to be studied were floated on the surface of the mercury.

The scientists knew their findings would be affected by temperature variations of as little as a hundredth of a degree. No thermometers in England were so sensitive to temperature. Work was halted until a new system of thermometry could be devised.

Early experiments with the measuring apparatus showed that direction and intensity of artificial lights would influence readings. Again work halted, until a new lighting system could be designed.

Now the work of comparisons began, and the dimensions of the task made everything that had gone before seem casual: more than

two hundred thousand readings! Every bar was compared with every other bar, not once but many times, in every possible position, and several men repeated identical experiments to minimize human errors.

After painstaking calculations, they began construction of new yard bars. Forty were made, and the series of comparisons repeated. The best of the new bars was chosen, and it is still, today, the ultimate standard of measure of the United Kingdom. Four other bars, designated as Parliamentary Copies, were deposited in four places of safekeeping. Other bars were distributed. Two came to the United States, and one became, for a number of years, our national standard of length.

After the fire, the scientists could find few reliable copies of the pound. Most of the specimens known to have been compared with the lost standard were useless, because they were so worn or oxidized. The scientists were satisfied with the reliability of only two. From them a new platinum pound was constructed, with four Parliamentary Copies, and additional copies for distribution. This platinum pound is also, today, the ultimate British standard. It is not a Troy pound; Troy weight was abolished for official purposes and the 16-ounce pound avoirdupois adopted.

These two units are the foundation of the British imperial system. From them most other units, such as the gallon and bushel, are derived.

There was another change in the imperial system, made by Parliament in 1824. Three years earlier John Quincy Adams had recommended that the United States adopt, as a national standard, the wine gallon, both because it was in common use and because, in his judgment, it was vitally important that United States measures be identical with English. But Parliament outlawed the wine gallon, as well as the old beer and ale gallons, and adopted a new unit, the Imperial gallon, the volume of 10 pounds of distilled water at 62° Fahrenheit. The United States has never followed this change; we have held to the old wine gallon, now obsolete in England.

So now, at last, measurement had become a science, and the responsibility for standards of measurement had passed into the hands of scientists. Whatever might happen in commerce, no matter how an individual shopkeeper here and there might tinker with his brass

weights or his scale, the fundamental standards of measurement would never again be uncertain or corrupt.

The work of the scientists was well done, so well that it has stood for more than a century. But as science and industry have progressed, so has metrology, and it seems that one day soon these old English standards will be superseded. The dimensions of a metal bar may change with time. The official British yard bar has, in fact, become somewhat shorter than it was, so that the British yard and ours are no longer identical.

In 1951, the British Board of Trade published the report of a special committee which had studied the current condition of British standards. The Imperial Standard Yard, the committee found, compares unfavorably with the International Prototype Meter, on which the United States standards are now based. Because the defining lines are rather coarse, accuracy of comparisons with the Imperial yard is limited to about 0.00002 inch, while the Meter, superior in workmanship and design, permits comparisons to 0.000004 inch. British law specifies that comparisons should be made at 62° Fahrenheit—but the committee found that no temperature scale had ever been legalized!

It was sharp in its criticisms of the Imperial pound. As mentioned earlier, the law calls the Imperial pound a "weight," but it must be used as a mass despite the law. It is about 70 parts in a million lighter than it used to be. And the law fails to explain how the commercial standards of England should be derived from the legal pound, since it is defined as a weight in a vacuum, without the buoyant effect of air, while all commercial weighing is done in air.

Such differences as these seem trivial, and until a few years ago they were almost inconsequential. But today, both scientific research and precision manufacturing require greater accuracy than these standards permit. The difference between the English and the American inch, for example, caused some difficulties in World War II, in the production of aircraft components by one country for use by another.

It is high time, the committee declared, that the United Kingdom get in step with the rest of the world. Most civilized countries have subscribed to the international metric convention and now base their

standards on the international meter and kilogram. The United States did this some years ago. We abandoned, for official use, our copies of the British Imperial standards. The National Bureau of Standards has no official yard bar, no official pound. Our yard and pound are derived from our copies of the international meter and kilogram.

The British committee went even further, making a radical recommendation. It urged that Parliament, once again, give earnest thought to adoption of metric units of measurement for all official purposes, allowing the foot, the pound, the bushel, the gallon and all of the other traditional units of the past to recede gradually into history.

5

MR. HASSLER'S STANDARDS

It would not be exact to say that the United States Congress ignored the powers given it by the Constitution to fix weights and measures. The need was explained in urgent messages from several Presidents and resolutions from state legislatures. Committees met, debated, called for recommendations and adopted resolutions. But, somehow, nothing more conclusive happened. Our national standards were, in the end, not promulgated by legislation, but by the initiative of a Swiss immigrant, a minor official of the Treasury Department, Ferdinand R. Hassler, in a remarkable usurpation of Congressional powers.

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At times it seemed that the Congress was on the verge of action, as in 1817, when Secretary of State John Quincy Adams was asked to consider the state of the nation's weights and measures and make appropriate recommendations. As a scholar, Adams did more than that, studying the history of standards, seeking the lessons of the past. As a statesman, he produced a report blending ideals and wisdom. But as the owner of a conspicuously orderly mind, he could not refrain from a few acid comments. Three generations of British Parliaments, he observed, had done nothing about the recommendations of the 1758 committee. Since the founding of the American Republic, he added, the Congress of the United States had pursued "the same cautious deliberation."

Would nothing persuade Congress to act? Washington had sent message after message on the subject of weights and measures, but the

most that happened was appointment of a committee or a request for suggestions. Now Adams was called on for still another report.

Some cautious deliberation was in order, to be sure, for the situation was badly muddled and becoming no better. Except for Dutch weights in New Amsterdam, French in Louisiana, and Spanish in Florida, the measures of the American colonies were almost wholly English in origin. How then could such diversity have come about? And why had the colonial legislatures been so insular, adopting standards unlike those of their neighbors?

Why had Connecticut fixed the bushel of wheat at 56 pounds, when her neighbors made it 60? Connecticut's bushel of oats weighed 28 pounds, but New Jersey's was 32, Kentucky's 33½. Missouri was putting 35 pounds of oats in the measure, while out in Washington Territory 36 was the standard. Even when a source could be identified, the explanation was not always clear. Mysteriously, the town of Alexandria, Virginia, used a bushel standard which had enjoyed a limited popularity in England about 1266!

They all used the same terminology, but this in a way made matters more confusing. The most hopeful fact was some simplification of the English vocabulary. The palm, link, nail, span, cubit, pottle, loom, wey, and last were seldom used in America, and the wine gallon had much greater popularity than the old beer and ale gallons. Even so, the list of terms was long enough, including such capacity measures as the firkin, kilderkin, strike, hogshead, tierce, pipe, butt, and puncheon.

George Washington, on taking office, urged the new Congress to use its Constitutional power and give the new nation a national, unified system of weights and measures. Congress set up a special committee to consider the matter, and in due course this committee asked our first secretary of state, Thomas Jefferson, for his recommendations. The request came at a most unfortunate time for Jefferson and for the country. Great events were taking shape in Europe. Jefferson knew a little about them, though by no means enough.

Some years earlier the Scottish instrumentmaker and engineer, James Watt, had written to scientific colleagues in France, urging that they and British scientists join in promoting a wholly new system of measurement. It was a period of revolutionary progress in the physical sciences, involving French and British scientists in close inter-

change. Watt was intimate with the leaders of science in both countries, active in the Royal Society in England, and in the informal but enormously potent Lunar Society, a dinner club usually called "The Lunatics."

Watt proposed that this new system be based on a fundamental standard of length, from which all other measures would be derived. Then he proposed to scrap the entire vocabulary of weights and measures accumulated over the centuries and make a fresh start. In the new system, all units would be related in decimal ratios. All parts and multiples would be decimalized.

The French scientists were responsive to the plan, for France at the time had no national system of weights and measures. Instead, there were the provincial units of the Bretons, Franks, Normans, Burgundians, Navarrese, British, Flemings, Helvetians, Italians, Basques, Provençals, and Moors. What was sold by weight in one town was sold by measure in another and by count in a third.

When Thomas Jefferson received the request from Congress, the French Revolution was under way. The Bastille had been stormed, an event celebrated by the Lunar Society, most of whose members were ardent pro-revolutionists. Prince Talleyrand, like many national leaders of the past, saw that unity of weights and measures was one key to national unity. He had directed the Royal Academy of Sciences to begin at once to construct a new system, based on the principles expounded by Watt.

News of this reached Jefferson soon after he began work on his report. It was no surprise to him. He knew the French scientists well, and had returned from five years in Paris only recently; and through Benjamin Franklin he had close ties with the British scientists in the Lunar Society.

Considering these facts, and his personal interest and ability in the natural sciences, what Jefferson did seems odd. At that moment, though perhaps he did not realize it, he was given an opportunity to bring the United States into what would surely have become a single, world-wide, unified system of weights and measures. Instead, he submitted a report which can only be described as ill-considered and incompetent.

When Adams received a similar request from Congress in 1817,

he gave the matter four years of research and thought before responding. Jefferson, never one for cautious deliberation, delivered his report in four months and apologized for his tardiness, explaining that he had been ill! True, he delayed a few weeks after hearing the news from France, and he made minor revisions then; but the report shows every sign of haste, including errors of simple arithmetic.

For all of his eager curiosity, his exploring mind, his wide-spread interests, and his boldness of thought, Jefferson was a conservative in scientific matters, holding to the precept of Pope:

> "Be not the first by whom the new is tried,
> Nor yet the last to lay the old aside."

In Paris, Jefferson had been present at the birth of modern chemistry. He was there when Lavoisier, de Morveau, Fourcroy, and Berthollet announced a new, simplified chemical nomenclature, the basis of our present system; and he knew of other achievements of Lavoisier, notably his refutation of the phlogiston theory. But he remained sceptical, and wrote that the attempt to revise nomenclature was premature, that it "may have served no other end than to have retarded the progress of the science, by a jargon, from the confusion of which time will be required to extricate us."

Lavoisier was a leading architect of the system of weights and measures being evolved in France. Jefferson, though he doubtless knew, from his own recent talks abroad, the general design of the system, had before him only Talleyrand's directive. Perhaps he could not have anticipated how sweeping a change this directive would inaugurate; and yet he could not have been ignorant of the objective sought by his scientific friends and acquaintances: a universal system.

Nevertheless, though he had condemned Lavoisier and his colleagues for innovation in nomenclature and the disturbance to customary usage, he did not hesitate to propose to Congress some radical innovations of his own. He offered Congress a choice between a simple consolidation of the existing system or a fundamental reform. He presented two plans, one for revision, one for radical change.

His revision was a patchwork, ingenious but full of inherent conflicts. On the whole, it would have conformed with the official standards of Great Britain, except in several places where relatively small

changes in the values of units would facilitate computation. For example, Jefferson proposed that by making the bushel 2,160 cubic inches, it would be exactly 1¼ cubic feet. This, he said, "simplifies the connection of measures and weights." So it would. But if the change had been adopted, the United States would have had a unique bushel, different from that of any other country.

He recommended adoption of a natural standard of length: the length of a pendulum beating seconds at a stated latitude. This was good theory, and the same proposal had been made by British scientists. Jefferson's report acknowledged that there were technical difficulties, but he described in detail how these could be overcome. He was over-optimistic. Fifty years later British scientists made extensive experiments with the pendulum and found unavoidable errors too great to permit its use as a natural standard. But these are petty flaws in comparison with those of Jefferson's radical plan, which he obviously preferred. Like Watt, Jefferson favored decimal units, which would "bring the calculations of the principal affairs of life within the arithmetic of every man." But he either ignored or rejected the scientists' wish for uniformity.

When Adams wrote his report three decades later, he made no direct mention of Jefferson or Jefferson's scheme. But he commented scathingly on the folly of confusion by terminology, applying the same name to different things. And this was just what Jefferson proposed to do: create a series of utterly new units of measurement, but christen them with the names of the units in current use.

His unit of length—a pendulum beating seconds—would be subdivided into five parts, each called a "foot", though this would be shorter than any foot measure then known in America. The new foot would be divided into ten units called "inches", which would be longer than the common inch. Ten thousand of the new feet would be a new "mile."

The Jeffersonian "bushel" would be a cubic foot—the new foot—and the bushel would be divided into a thousand "metres," a new term, which the French were about to adopt for their unit of length. Jefferson's new "pound" would contain ten ounces. And so on.

Thus offered two choices, Congress selected neither, and did nothing. George Washington gave them a little time, then renewed his

plea for action. But by then more news had arrived from France and England. The plans for a new international system were progressing. There was good reason to wait.

The next year a third message from President Washington prompted the Senate to appoint a special committee. Five months later the committee brought back an astonishing report: it recommended adoption of Jefferson's radical plan! Perhaps startled, the Senate did nothing.

That is to say, it did not act. It often seemed on the verge of action. Debate was postponed from day to day. Someone introduced a resolution calling for adoption of the committee report. Someone else offered a resolution favoring Jefferson's more moderate plan. A third resolution simply called for action without specifying what should be acted upon.

Three years passed, and the new French system had taken shape. It had a name: the Metric System. The Committee of Public Safety invited all other nations to join with France in making it world-wide, and Citizen Dombey was appointed as special ambassador to bring the invitation to the United States. But Dombey died on the way, and his papers were temporarily lost. Some months later they were recovered and sent to the French Ambassador at Washington, who presented them to the President. Washington sent them on to Congress, and copies were printed for all the Members.

Its patience sorely tried by all these proposals, the House of Representatives sulked for a few weeks, then burst out in a flurry of action, voting down everything in sight—both of Jefferson's plans, the metric system, and various committee proposals. United States measures, declared a House resolution, should be "those now in use"—whatever that meant. It might be a good idea, perhaps, to relate these common measures to some kind of a standard, but only if it could be done "without much time, trouble, or expense." When the Senate was asked to concur, someone proposed an appropriation of a thousand dollars, but his was a lonely voice.

By 1799 the pressure on Congress had increased. There were complaints from abroad that international trade with the United States was somewhat chancy, because collectors of customs had very personal ideas as to the weight of a pound or the size of a bushel. If a shipper

landed his cargo in New York, he might pay ten percent more import tax than if he docked in Philadelphia. To remedy this state of affairs, Congress passed a bill directing that sets of standards be furnished to the collectors of customs. It was an excellent idea, but for the small difficulty that there *weren't* any national standards. But anyway, Congress failed to appropriate any money, so the executive branch was relieved of responsibility, and customs collectors continued to use their own judgment.

And so it went. State legislatures sent memorial after memorial to Congress, pleading that something be done, for interstate commerce, as well as foreign trade, was hampered by disputes. President Madison urged action, and gave his support to Jefferson's reform scheme. Committees were appointed and discharged, bills introduced and allowed to die unreported.

Perhaps, in those days, no one cared to speak out in public on what was clearly one of the principal reasons for delay. But it was there: What was Great Britain going to do about the metric system?

If Britain decided to join France and other nations in adopting the metric system, then the United States would have no choice other than to follow. But if the rest of the world did not unite, Britain retaining her traditional standards while France developed new ones, then which of the two should the United States choose? Ties with both England and France were strong, and the pattern of future commerce was uncertain.

Had Jefferson been less hasty, had he known more and understood more of what was happening in Europe, the United States might be a metric country today. His was the first and probably the easiest opportunity to bring about a change. But the moment passed, and a few years later the metric system was under heavy attack.

Even in recent years metric measurement has been denounced for its origins: "At its birth the offspring of revolution, it has remained the child of force." In the aftermath of the French Revolution, all of the Revolution's works were denounced. Against the metric system there was religious feeling, too, for the Committee of Public Safety had included calendar reform as part of the plan: the Sabbath was abolished; the week had ten days, the month three weeks, and the

twelve months were given Revolutionary names. One day a year was dedicated to the Lord, five, at the year's end, to what some termed a pagan festival.

The scientists who had designed the metric system were no longer able to explain and defend it, for most of them fared badly during the Terror. Lavoisier went to the guillotine. Others were in prison, under house arrest, or in exile.

What was more, the new system was losing public favor even in France. Efforts to enforce it failed. When Napoleon became Emperor in 1805, confusion was wide-spread: old units persisted in use; new names were sometimes applied to old units, old names sometimes applied to the new. Napoleon contrived to make matters worse by sanctioning what he called "mesures usuelles."

This, then, was the situation when John Quincy Adams was asked to prepare a new report. There was another reason for him to be hesitant, too. The Congress had adopted one major reform: decimalized currency, and the results had not been altogether happy.

Currency reform had seemed necessary and inevitable. The new nation must have its own money. Why not, then, break away from the cumbersome pounds, shillings, and pence?

English currency was familiar in all of the colonies, of course. But there were colonial currencies, too, such as the "lawful money of New England," including the pine-tree shilling, using the English terminology. Merchants also accepted payment in Irish money, Halifax money, pistoles, moidores, pieces of eight, johannes—almost any coin that had a solid ring and a reputation.

The new United States currency promptly established a reputation, of a sort: because of its metallic value, it was more profitable to export it than circulate it! For domestic exchange, foreign coins were more familiar than United States money for some years. And the idea of decimalization was poorly understood. Dimes, when they began to appear, were often offered and accepted as eighths of a dollar, rather than as tenths. Indeed, there were local rates of exchange between the denominations: a dime was worth ninepence in Richmond, eleven in Baltimore, twelve in New York.

"Two bits" was not a slang expression then. A "bit" was a segment

of a piece of eight, so the United States 25-cent piece was not a "quarter" to the average man, but two eighths, or bits. In other places it was often called a "shilling," and this usage persisted in some New England communities well into the nineteenth century.

So Mr. Adams was not inclined to hurry, or to add still further to the confusion. But at this time, perhaps the most difficult and uncertain in the history of measurement, he wrote a report which is one of the few classics of metrology.

Better histories of measurement have been written. Adams contributed nothing new, factually, and as his ancient history he offered the Hebraic legend that Cain, after his wanderings, built a city called Nod and became the author of weights and measures. His history of English measure was drawn almost exclusively from the Parliament report of 1758. But where that committee had been content to assemble and recite the ancient statutes and declarations, Adams provided brilliant analysis, pointing out how ambiguous language in a given statute had been misinterpreted, how other language had been perverted or ignored.

Adams was no metrologist, but he had an asset Jefferson lacked. At his elbow was the only man in the United States who could qualify as an expert, a Swiss immigrant, Ferdinand Hassler; and Hassler had just returned from several years in Europe where he had watched the progress of the metric system, visited instrumentmakers, and talked with leading scientists, many of them old friends. Further, Hassler had brought home a collection of physical standards—bars and weights, copies of the most authoritative standards of England and Europe.

With Hassler's help, Adams directed the first comprehensive survey of weights and measures used in the United States, gathering evidence of the well-known fact that discrepancies were more common than uniformity. He collected the weights and measures laws of the colonial legislatures and traced, as best he could, the origins of the physical standards used by the states, from the very beginning, 1641, when the legislature of Maryland enacted the first weights and measures law on this continent.

Throughout history, Adams wrote, reforms had had but one object:

> "When weights and measures present themselves to the contemplation of the legislator, and call for the interposition of law, the first and most prominent idea which occurs to him is that of *uniformity*: his first object is to embody them into a system, and his first wish to reduce them to one universal common standard. His purposes are uniformity, permanency, universality: one standard to be the same for all persons and all purposes, and to continue the same forever."

Why had all of these reforms failed? Why the long history of confusion, the degradation and collapse of systems?

> "These purposes, however, require powers which no legislator has hitherto been found to possess. The power of the legislator is limited by the extent of his territories and the numbers of his people. His principle of universality, therefore, cannot be made, by the mere agency of his power, to extend beyond the inhabitants of his possessions. The power of the legislator is limited over time. He is liable to change his own purposes. He is not infallible: he is liable to mistake the means of effecting his own objects. He is not immortal; his successor accedes to his power, with different views, different opinions, and perhaps different principles. The legislator has no power over the properties of matter. He cannot give a new constitution to nature. He cannot repeal her law of universal mutability. He cannot square the circle. He cannot reduce extension and gravity to one common measure. He cannot divide or multiply parts of the surface, the cube, or the sphere, by the uniform and exclusive number ten.
>
> "The power of the legislator is limited over the will and actions of his subjects. His conflict with them is desperate, when he counteracts their settled habits, their established usages, their domestic and individual economy, their ignorance, their prejudices, and their wants: all which is unavoidable in the attempt to change, or to originate, a totally new system of weights and measures."

Here, indeed, was a fresh point of view! The reformers of the past had put the question differently: to them it was always a struggle be-

tween sin and virtue, between upright men and those who practiced "great Deceit." Always in the past the remedy offered had been the same: a better law, and stronger enforcement.

Not so, warned Adams. The power of the legislator is not enough to achieve uniformity, and the obstacle is not wickedness but the people themselves.

Adams was one of the first—and, indeed, one of the last!—men to consider the merits of English and metric systems judiciously and dispassionately. So successful was he in this that both metric advocates and opponents have quoted him liberally ever since, and their debates with each other often sound like vulgarizations of Adams' debate with himself.

It was a dilemma. He deeply admired the qualities of the metric system. All other systems of measurement were accidents of history, evolved piecemeal, altered by chance and whim, varied by error, abused by design, carelessly preserved, with units so awkwardly related as to ill deserve the designation "system."

And here was the metric system, created by the world's best scientists, a system of order and logic and simplicity:

> "The spectacle is at once so rare and so sublime, in which the genius, the science, the skill, and the power of the great confederated nations are seen joining hand in hand in the true spirit of fraternal equality, arriving in concert at one destined stage of improvement in the condition of human kind . . . The scene formed an epocha in the history of man. It was an example, and an admonition, to the legislators of every nation, and of all after-time."

But, perhaps, was it a little *too* sublime? he asked. Had the scientists, in their exclusive partiality for decimal arithmetic, been wise to overlook the physical organization and habits of men? Were men ready and willing to abandon the traditional units which they could approximate, roughly, by reference to their own fingers and hands and arms and feet? Were craftsmen willing to accept decimal units, which have the greatest ease in *computation,* in the place of units divisible by 2, 3, and 4, which are more easily manipulated by *judgment?*

So Adams, like Jefferson, offered Congress a choice, but his alterna-

tives were not Jefferson's. His conservative plan was even more conservative: tie the American system firmly and uniformly to the English, permitting no deviations. And his reform plan was also conservative: adopt the metric system, without a single variation.

He warned that change not be undertaken lightly: "Change, being itself diversity, and therefore the opposite of uniformity, cannot be a means of obtaining it, unless some great and transcendent superiority should demonstrably belong to the new system to be adopted."

Was there not a Constitutional question? Congress had been given power to fix weights and measures. Was this grant broad enough to sanction the subversion of an existing system and the adoption of a new one?

There was, he wrote, a simple path to uniformity within the nation itself. The United States already had uniformity in theory. To achieve uniformity in fact, it would be necessary to do little more than adopt positive national standards and provide copies of them to the several states. Perhaps this would be the wisest course. Yet he could not turn his back on the "sublime spectacle" across the seas.

In time, he said, he believed all nations should adopt the metric system. He urged that the United States open conversations with all friendly nations to promote this objective.

And yet he wondered,—"Where is the steam engine of moral power to stem the stubborn tide of prejudice, and the headlong current of inveterate usage?"

Once again offered alternatives, Congress chose neither, and continued its "cautious deliberations." Resolutions bloomed and faded. Four years later, in 1825, Adams became the sixth President of the United States, but he had nothing more to say on the subject. The nation entered its second half-century without national standards, the pleas of its first President and of the states as yet unanswered.

But one man, at least, had not forgotten Adams' report: Ferdinand Hassler, who had helped prepare it. Soon after Adams was defeated in his campaign for a second term, Hassler found a way to do what Congress had never done.

If Hassler was less than overawed by the power and wisdom of Congress, he had some justification. As a young man, he left an en-

gineering career in Switzerland to become a mathematics instructor at West Point. In 1807 Congress directed that a survey be made of the coast. Hassler, who had planned the first scientific survey of Switzerland, submitted a proposal to the Secretary of the Treasury. It was accepted, and Hassler was brought to Washington as the first superintendent of the Coast Survey. It was an impressive title, but when Hassler arrived he found a title was all he had. Congress had provided no money for the survey.

At last some money was forthcoming. The first step, then, was to buy surveying instruments. None were manufactured in the United States. So Hassler sailed for Europe to buy them, but was unable to return for several years, because war broke out with England in 1812.

He had no sooner returned in 1815 than Congress changed its mind and transferred the Coast Survey to the Navy Department. After the Navy had done nothing remarkable about the survey for several years, Congress shifted it back to the Treasury. But Hassler had no more than begun to organize a staff when word came down from Capitol Hill: the survey had been sent back to the Navy! After a while there was another Congress, and Treasury, on the fourth bounce, managed to hang on. The Coast Survey never went back to the Navy, though some years later it was transferred to its present home in the Department of Commerce.

Hassler realized what Congress apparently did not: that if one is to measure something, whether it be a yard of linen or a coastline, one must have a standard of length. Since Congress did not seem disposed to adopt a national standard, Hassler was quite willing to adopt one all by himself! On his trip to Europe he had acquired the best available copies of the English, French, and metric standards of length. He had also acquired copies of the Troy pound and the kilogram.

In 1830, while the Coast Survey was on one of its visits to the Navy Department, Congress asked the Secretary of the Treasury to have a look at the weights and measures being used in customs houses, because, after more than fifty years, complaints were still coming in. Hassler had nothing to do at the time, and he was clearly the best-qualified man to do the job. So the Secretary of the Treasury, Samuel D. Ingham, gave Hassler the assignment.

It was the same old problem: If a pound weight in the New York

customs house was to be tested, with what could it be compared? But there was one difference: In 1828, Congress had legalized a pound weight for use by the Mint, a brass weight obtained by the American ambassador to Great Britain. Except in its use by the Mint, it had no legal status. But Hassler, having ascertained its close relationship to the British Troy pound, accepted it as his standard, and went ahead, going far beyond his instructions, for he broadened the survey to include the standards of all government departments and states, as well as those of the customs houses. His conclusion was the expected one. There were scarcely two specimens of weights and measures in the customs houses that agreed within reasonable tolerances. Congress received his report. A resolution was introduced. Cautious deliberation resumed.

But Mr. Hassler was not going to wait for Congress. With the support of President Jackson's second treasury secretary, Louis McLane, and without the slightest authority in law, he proceeded to do precisely what John Quincy Adams—no doubt at Hassler's suggestion—had recommended! He set up shop in a nearby arsenal. He decided what the national standards of weight and measure should be. And, having adopted standards, he began manufacturing copies of these standards to distribute to state governments.

For his—or, rather, our national—standard of length, Hassler chose a bar made by the English instrumentmaker Edward Troughton. Hassler knew that this particular bar, though carefully made, had never been directly compared with the Parliamentary Yard, and he stipulated that if any discrepancy should later be discovered, the Parliamentary Yard should be accepted as the ultimate authority.

This Troughton scale was a bar 82 inches in length, subdivided into inches. After many measurements, Hassler defined the official yard as the interval between the 27th and the 63rd inch marks.

As it turned out, there was never an opportunity to make this comparison, for the Parliamentary Yard was destroyed by fire. When the new imperial yard was reconstructed, forty copies were made, and two were presented to the United States. One of them, Bronze No. 11, compared with the Troughton scale, was found to be 0.00087 inches shorter. The Treasury Department then discarded the Troughton

scale, and Bronze No. 11 became, for a time, the accepted standard.

Hassler designated the Mint pound as the standard of weight, but it was, of course, a Troy pound, not an avoirdupois pound. He derived the avoirdupois pound from it, and constructed copies.

Two of Hassler's decisions were at variance with Adams' recommendation that no differences be permitted to exist between British and American standards. For liquid measure, Hassler adopted a wine gallon which Britain had legalized in 1707 but abolished in 1824. And Hassler's bushel was the old Winchester bushel, which had also been abolished in England. Under the circumstances, even Adams might have approved Hassler's judgment. The wine gallon and the Winchester bushel were the units most widely used in the United States. The new imperial gallon and bushel were unknown here. Perhaps a minor government official could standardize existing units. But he would have no chance of bringing about a drastic change single-handed.

In time, Congress discovered what Hassler was up to. Faced with this unusual usurpation of Congressional powers, a committee of the House adopted a resolution—urging Hassler to hurry!

Then, in 1836, Congress, perhaps unconsciously, paid a high tribute to this Swiss immigrant. Both houses passed a resolution directing the Secretary of the Treasury to do what Hassler had, in fact, been doing: to supply the states with sets of standards. The resolution referred to "all the weights and measures adopted as standards." The only ones "adopted" were those adopted by Hassler!

The states were as prompt as Congress had been dilatory. Congress had directed that one set of standards be provided to each state. Hassler thought two would be better, so he decided to furnish two. As rapidly as they were received, most state legislators recognized them as the sole legal standards within their borders. This was the beginning of our national standards. Though Bronze No. 11, the Mint pound, and Hassler's other units are no longer the fundamental standards, from this time forward there was order and continuity.

Hassler died before his project was completed; but others carried it on, and the Office of Weights and Measures, within the Treasury Department, made executive decisions, adopting and modifying na-

tional standards, until the National Bureau of Standards was created by Congress in 1901.

But the metric system was far from dead, as an issue. After 1840 its status was never in doubt in France, and nation after nation adopted it, discarding their medieval, feudal, provincial systems. In 1866, as metric advocates are fond of pointing out, the metric system became the only system *legally recognized* by the United States!

The statement needs qualification. Congress did two things: First, it said that metric units *could* be used legally in any business transactions. Second, it adopted and published a table showing the official conversions of United States to metric units, and vice versa. What gives this legislation an odd flavor is that our own units have never been given similar Congressional recognition! They rest on a foundation of state laws.

A quarter-century later, another decision was made, linking the United States more closely to the metric-using nations. Since 1893 the United States has had no official yard bar or pound weight. Our fundamental national standards are the meter and the kilogram.

In 1875 the metric system became international, as Watt and Talleyrand had hoped it would. Seventeen nations, including the United States, met in an International Conference on Weights and Measures, and agreed to set up an international bureau. Committees of specialists were appointed to construct new and permanent standards, technically superior to those constructed in the midst of the French Revolution.

The work was completed in 1889. For all of the nations signing the metric convention, the ultimate authority for the meter and the kilogram are the specimens kept safe in a vault, deep in the ground beneath an international reservation near Paris, where they lay undisturbed through two world wars. Copies of these standards were made and distributed, by lot, among the member nations. At a ceremony in the office of President Benjamin Harrison, one each of our copies, Meter Bar No. 27, and Kilogram No. 20, were unpacked.

So, today, our standards and those of the metric nations are bound together in an unvarying relationship. Our vocabulary is English, but our units are not English units. Our bushel and gallon are not those

of England; the units we adopted had previously been abandoned in the United Kingdom.

It is more disturbing to learn that our inch and pound are not identical with British units—for they were supposed to be, and it was Hassler's intention that they should be. Over the years, the relationships between the fundamental British yard and pound, and the fundamental international meter and kilogram, have changed, through natural processes, slightly but significantly. Thus our inch, based on the meter, has come to differ slightly from the British inch.

Will true uniformity ever be achieved?

There have been times when it seemed very near. Indeed, there was one certain day when world-wide uniformity could well have been achieved, and the opportunity was lost by a political accident, an error of judgment made by a single Congressman!

6

THE GREAT METRIC CONTROVERSY

THIS YEAR, PERHAPS, SOME CONGRESSMAN WILL INTRODUCE A BILL which, were it to pass, would make metric measurement the only legal system in the United States. It will not pass; indeed, it will die in committee. But there was a time when passage of such a bill seemed certain.

The Great Metric Controversy began in 1799, and it will continue so long as there are two systems of measurement in the world. Though a change seems unlikely today, the debate continues sporadically in the popular and technical press.

It has been a strange debate. Measurement may not seem an emotion-stirring issue, yet few of the participants have managed to keep their tempers, and on both sides the arguments have been loud and inflammatory, well laced with personal attacks. Advocates have claimed the United States could convert to metric measure in a few weeks, and that the cost of the change would be recovered in a few months. The cost would be tens of billions, opponents replied, and it could never be recovered. Thousands of businesses would fail, and millions would be unemployed.

Almost everyone would welcome it, advocates say. On the contrary, opponents retort; it could never be enforced and the jails would bulge with violators.

Some very distinguished men have asserted that the metric system would save two or three years' time in the education of a child.

Equally distinguished men have branded this utter nonsense; if there were any saving, it would be less than a week. According to its critics, the metric system violates the laws of nature, man, and God. It drove American engineers mad in World War I, and made cripples of customs inspectors.

A forgotten pamphleteer wrote:

> "Modern science, disguise it as we may, is not merely far at sea upon the waves of doubt, but is essentially an atheistic school, that has no God, and which has long since closed its doors against the written Word. Our representatives have no more right to force the metric system upon us than they have to make our babies beg for bread in foreign idioms . . . Even the permissive use of the metric system is a blot upon our statute books. If men want to use an evil system, they will do it anyway."

As if God and Christianity were not enough, some anti-metricists claimed paganism and superstition as allies. They wrote involved dissertations on ancient symbols as guides to "cosmic truths," and professed to find in the mystic numerical ratios of these symbols the foundations of the English system of measurement.

The metric system has had many famous men as advocates: Andrew Carnegie, Lord Kelvin, General Pershing, General Gorgas, Thomas Edison, George Westinghouse, Henry Ford, Luther Burbank, Franklin Delano Roosevelt, Fiorello la Guardia, Samuel Gompers, Otto Kahn, Alexander Graham Bell, and others. In general, scientists and educators have been almost solidly in favor of it. The opposition has not been quite so sharply delineated. Some industrial groups have favored it. Others, chiefly the metal-working industries, textile companies, shoe companies, and machine tool fabricators, have been opposed. In tests of strength, the opposition has won.

For a number of years the issue has seemed almost dead in the United States, and the organizations set up to promote metric legislation have virtually disbanded. But in England, in 1951, a distinguished committee, appointed by the Board of Trade, recommended to Parliament that Britain adopt metric measure for general use. Fifty years ago, when it seemed certain that Parliament would adopt metric legislation by an overwhelming vote, it was the Board of Trade,

then headed by Lloyd George, which succeeded in a last-minute maneuver to block such legislation.

Events in England have great significance for the United States. Always in the past the two nations have followed nearly parallel courses on this question: When the controversy was hottest here, it was hottest there. And everyone knew, and the opposition freely admitted, that if one should make the change, the other would quickly follow.

Beginning in France, the metric system spread throughout the world, displacing in nation after nation the ancient or feudal systems of measurement. To be sure, its extension has not been universal. Vestiges of ancient units remain everywhere, as metric opponents gleefully report. Chinese shopkeepers may still use ancient weights, and Spanish units are not uncommon in Latin America. Some trades still cling to old ways. It is also true that English-American measure is familiar to commercial houses throughout the world, and that World War II plus our foreign assistance programs have increased this familiarity.

But this is cold comfort for advocates of English measure. The metric system has become the sole official system in nation after nation, sweeping around the world, becoming the first international language of measurement. Of all rival systems, only the English and American have withstood it, and even they have lost ground. There is not the slightest chance that our system should become a world system. If the world is ever to have a single system of measurement, it will be the metric.

It has invaded both Britain and America. Much of our scientific work is conducted in metric units. The electrical industries use the same units throughout the world; they are decimalized and part of the general metric system. Metric units are widely used in the chemical and pharmaceutical industries. Though American automobile makers work in feet and inches, British makers have partially metricized their dimensions.

The future of metric measurement in the English-speaking nations is related, both directly and incidentally, to the present discrepancies between English and American standards, a matter which has given

much concern to scientists and engineers of both nations. We have common units, but we do not have common standards.

The United States inch is, legally, 25.40005 millimeters. Our fundamental standard of length is the meter. Thus the relationship between our units of length and metric units is fixed and unvarying. The English inch, not legally tied to the meter, has been changing over the years. It is now known to be 25.39993 millimeters.

The difference between American and English inches, 0.00012 millimeters, seems small, and it is too small to concern carpenters or stonemasons. But it is more than enough to cause difficulties in precision industries.

Standards associations in the two countries have adopted an intermediate value, 25.400 millimeters, for industrial use, and the Canadian Parliament has made this the legal equivalent of the Canadian inch. It has been proposed that Britain and the United States do the same. The change would have one practical value, which, incidentally, would make it somewhat easier to convert some industries to the metric system. The new value is a convenient number; for example, by using gears with 127 teeth—this being half of 254—machine tools and measuring instruments could readily be converted from one system to the other.

Like so many proposals in the world of measurement, this seems so eminently reasonable that one wonders why anyone should hesitate. But, as usual, there are complications. The change would make our inch shorter by about two parts in a million. The mile would thus be a little more than a tenth of an inch shorter, hardly enough to enable Messrs. Bannister and Landy to set a new world's record. From coast to coast the total difference would be about ten yards, not enough to require changes in highway maps. But what about other maps, such as those of the United States Geological Survey? Would all of the permanent markers have to be relocated? Or would someone undertake the formidable task of changing the measurements given in thousands of legal documents?

One change seems virtually certain. Sooner or later, and probably in the near future, Parliament will abandon the English physical standards and adopt the meter and kilogram, as the United States did years ago. But will English units—our foot, pound, quart, and bushel—

ever be abandoned? Will the world ever have a single universal language of measurement?

It could have happened, and on a number of occasions it almost happened. Mischance, misfortune, and the poor judgment of a few men were all that kept it from happening. The United States might well have adopted metric measure when the nation was new and the time propitious. Congress had rejected English units for the new currency, adopting a brand-new decimalized system. Our bonds with France were strong.

What would Congress have done if Thomas Jefferson had proposed, unequivocally, that we accept France's invitation to participate in founding a universal system? For that matter, what would have happened if Citizen Dombey, the metric system's ambassador, had not died on his way to the capital at Philadelphia?

Then for a time the system fell into disrepute, so that Adams, admiring its merits but recognizing that it might collapse, could not recommend its adoption to Congress. But he did urge that the United States enter into discussions with other nations to the end that all might eventually adopt it.

If Congress had done as he asked, the change might have come within a few years, for by then the metric system was solidly established in France and it was spreading to other countries. Congress did legalize the system for use in the United States in 1866, and in 1875 the United States subscribed to the Metric Convention.

The change could have been made quite easily in those years. There would have been little opposition. There were few industries to be affected. But, unfortunately, there was no substantial group of advocates. Scientists were few and not very articulate. Hassler was dead and no outstanding metrologist had taken his place. So it was both too soon and too late. One man of Adams' stature might have been enough to achieve the transition.

It was a different story in 1896, and in the years immediately following. American science was coming of age, and organizations of scientists were virtually unanimous in declaring that only metric units were suitable for scientific purposes. Exporters saw great advantage in adopting the units of measure used by most of the nations with whom

they traded. The burgeoning electrical industry was committed to metric units. Indeed, most of the newer industries of the United States were eager to take advantage of the metric system's simplicity, which would save money in designing, tooling, operations, and personnel training.

Congressman Southard of Ohio introduced a bill to make metric measure mandatory in all government departments and in all federal contracts. Scientists and educators appeared before his Committee on Weights and Measures to commend the bill. Resolutions, most of them favorable, came in from chambers of commerce, engineering societies, exporters' associations, educational groups.

The critical year was 1902, and nothing seemed to stand in the way. "It is as sure as anything in the future can be sure," said a Milwaukee newspaper, and that summed it up. The New York *Times,* one of the few newspapers opposed to Southard's bill, conceded that the bill would pass by a large majority vote. Secretary of Commerce and Labor Shaw, a vigorous supporter of the bill, declared that there was only one question: Would Britain or America act first?

There was some opposition. The Navy's chief construction engineer, for example, objected, on the grounds that the bill would make utter chaos of naval construction and maintenance. Mr. F. A. Halsey, editor of the *American Machinist,* wrote blistering editorials and delivered no less blistering speeches, attacking the metric system, the Southard bill, the claims of its supporters, and the purity of their motives. But when a committee of the American Society of Mechanical Engineers, led by Halsey, began making public statements to this effect, the Society silenced them by discharging the committee.

Southard's committee reported the bill with unanimous approval. The Rules Committee set a day for debate, early in July 1902. Ordinarily Congress would have adjourned by then, but the Department of State had an important matter to come up, a bill terminating United States military rule in Cuba.

Something happened in the diplomatic maneuvering, however, and word came to Capitol Hill that the Cuban settlement would not be ready for consideration. It was moved that Congress adjourn, and Southard didn't object. This was only the first session. His bill would be on the calendar early the next year. Washington summers are hot,

and, anyway, the metric question had been open for so long, more than a century, that another six months could do no harm.

Southard was troubled when Congress reconvened, for during adjournment the opposition to his bill had increased. It wasn't serious; he still had more than enough votes to pass it; but it was disturbing, because the attacks had become intemperate and at times rather too personal. The objections, he felt, were based on misunderstanding. The critics couldn't have read his bill. They said it would make the use of metric measures mandatory on everyone, and he had been careful to explain that it would be mandatory only within the government. The textile and shoe industries had protested. If he could only explain to them that they could go right on using their present units, he was sure they would withdraw their objections.

In retrospect, it is difficult to understand why Southard did what he did. An easy victory was within his reach, but he delayed. Then, in mid-session, he suddenly withdrew his own bill!

It wasn't a change of heart, or even loss of heart, for in later years he reintroduced it and tried to push it through. His only explanation was that he wanted time to win over the opposition. The New York *Tribune,* in favor of the bill, agreed that he was wise.

Whatever his reasons, the decision was disastrous. In the next Congress and the one following he might still have mustered a majority on the floor. But now the opposition was aroused and organized, and the lobbies were careful to see that the bill was bottled up in committee, where five votes were enough to smother it.

F. R. Halsey became a leader of the opposition; indeed, he spent the next twenty years campaigning against the metric system. Though his committee had been rebuked for impropriety by the American Society of Mechanical Engineers, his editorials continued, and they had effect, for when the A.S.M.E. membership finally was polled a majority was anti-metric. ASME

Once aroused, the opposition descended on Southard's committee, and the hearings were stormy, witnesses hurling charges of fraud, forgery, deceit, conspiracy, lying—everything short of treason, and not very short of that.

By any reasonable counting of noses, the proponents were still more numerous. But the proponents were not up to this kind of brawl.

Scientific societies passed resolutions and issued statements, and their spokesmen presented admirable testimony. But they were innocent of political strategy, especially where it counted, in finding the pressures to line up five votes in an executive session of a committee.

Why all the fuss? What were the underlying issues?

Fundamentally, they were not new. Indeed, they were thousands of years older than the metric system itself, older than the civilization of the British Isles, and the circumstances giving rise to them were as old as man.

The controversy began with man's natural endowment, the manner in which nature shaped his body. He had ten fingers. He counted on his fingers, and he measured with them too, and with his hands, arms, and feet. But there was no relationship at first between *counting* and *measuring*. Nor did man in those days *compute*. He counted. He did not add or subtract, multiply or divide.

The units of linear measure—foot, nail, cubit, span—were not chosen *because* they were related to each other in simple ratios. Nor did man begin counting on his fingers *because* he had ten. The ratios were discovered later, and by then decimal counting was well established.

The early refinements of measurements were very simple, more in the nature of mechanical operations than of number-work. As craftsmen gained skill, they required more precise units of measure. To obtain a unit smaller than a foot, for example, it was better to subdivide the foot than resort to another kind of unit.

Suppose you wish to subdivide a pie, or a lump of clay, or a strip of paper, into a number of equal parts, using no measuring instruments. You can easily divide the whole into halves, and the halves into halves, and you can verify your accuracy by comparing the pieces. With somewhat less ease, but with fair accuracy, you can subdivide into thirds. You would divide into quarters, of course, by halving and rehalving. But if you should attempt to subdivide into fifths or tenths, your margin of error would be considerably larger.

From these beginnings came the structure of present-day English measure: the 12-inch foot, the 3-foot yard, the 6-foot fathom, and so on. From the craftsman's subdivisions came the divisions of the inch into halves, quarters, eighths, and sixteenths; and similar subdivisions

of the gallon, quart, mile, ton, and pound. Ratios of 3 : 1 are found in linear measure because of the proportions of the human body. In the units of weight and capacity, where these proportions are not relevant, the ratio of 2 : 1 is general.

The influence of *computation* appeared when men began to develop units *larger* than those they could readily manipulate, and to relate them to the common units. For centuries short distances were measured by parts of the body, but long distances were stated in another kind of unit: the day's journey. Smaller units could be developed by mechanical subdivision. Slightly larger units could also be devised by adding, or doubling. But when still larger units were needed, or a unit such as the day's journey was to be given a numerical relationship to linear units, they were, in many instances, *computed.* And with computation began the application of decimal arithmetic to measurement.

What of the mile, for example? It would seem that our mile was developed through the halving-doubling process, since there are 8 furlongs to the mile, and so on. But this is a strictly English invention. The Roman mile was computed decimally: it contained 5,000 feet. The old English mile, introduced by the Romans, was a 5,000-foot mile. It was a revision begun in the reign of Henry VII and completed by Elizabeth that led to the 5,280-foot mile. There are other examples of decimal multiplication: the hundredweight and the short ton; the 100 links to the surveyor's chain, and 10 chains to the furlong.

Further, as need arose for extremely small units, decimal division was sometimes adopted in place of halving. In the United States, for example, machinists worked in fractions of an inch down to the sixty-fourth. Beyond that point fractions became unwieldy, and they now divide the inch decimally, into thousandths.

Measuring and counting existed side by side for many years, but until Arabic numerals replaced Roman in the Middle Ages computation was a real difficulty. When science and commerce began to use computation, however, the conflict began. Not only was there awkwardness in applying decimal arithmetic to measurement; there was an even greater problem in making conversions, moving from one kind of unit to another—bushels to cubic inches, for example.

The most persuasive demonstration of this is the almost universal illiteracy of English-speaking people with respect to their own system of measurement. For example, how many of these questions can you answer without consulting a reference book?

How many cubic inches are there in a bushel? A dry quart? A liquid quart?

What is the relationship, in capacity, between a dry quart and a liquid quart?

How many square feet in an acre?

How many acres in a square mile?

How many quarts in a barrel?

How many pounds of water will a barrel hold?

If a pint of a certain liquid weighs 1¼ pounds, how much will a cubic foot of it weigh?

How many cubic inches in a cubic foot?

In a cubic yard?

In metric countries, using metric units, any schoolboy can rattle off the answers to such questions without thinking twice. All of his units are decimal units, all related in ratios of ten, and the system is consistent throughout. A liter is a liter, wet or dry.

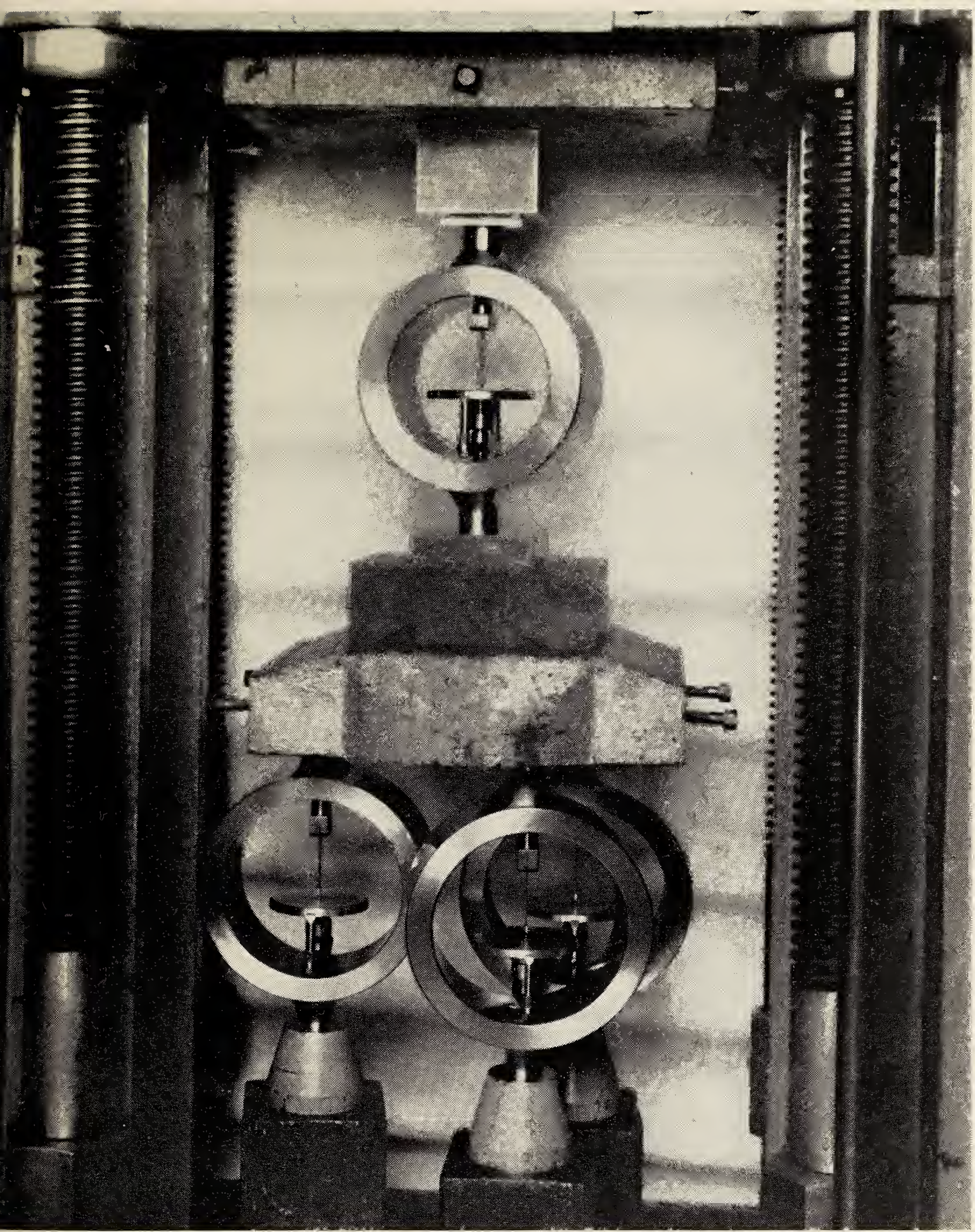
The English system, where subdivisions are conveniently expressed in fractions (½, ¼, ⅓), is well suited to the needs of nonprecision crafts. But fractions are not easily used in computations, and if the measurements are carried to finenesses such as 1/256, computation becomes laborious. Conversion of these fractions to decimals doesn't help much. One-half is a convenient 0.5. But ¼ is 0.25, ⅛ is 0.125, 1/16 is 0.0625, and ⅓ is 0.3333. . . .

For multiplication and division, decimal units are much quicker. For example: how much is 1.2 pounds of cheese at 63¢ per pound?

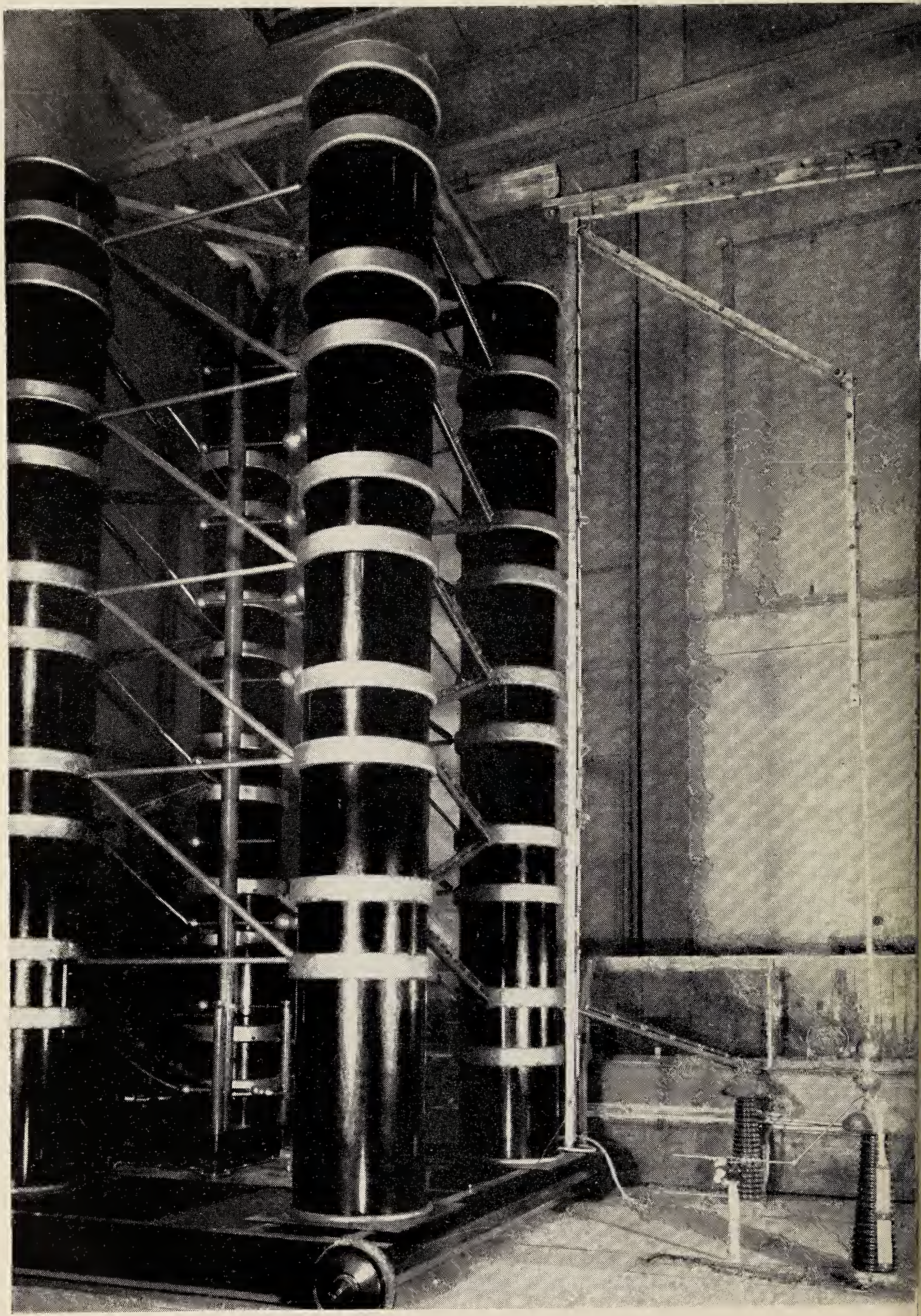
Well, then, how much is 1 pound 5 ounces of cheese at 57¢ per pound?

Or imagine that you are an English cheese merchant: How much is 1 pound 7 ounces of cheese at 3 shillings threepence per pound?

Perhaps there is, in such simple problems of computation, some clue to why proponents of metric measure have been, in some instances, almost violent in their advocacy! For the problems of the cheese merchant, even if he wrestled with such fractions a hundred

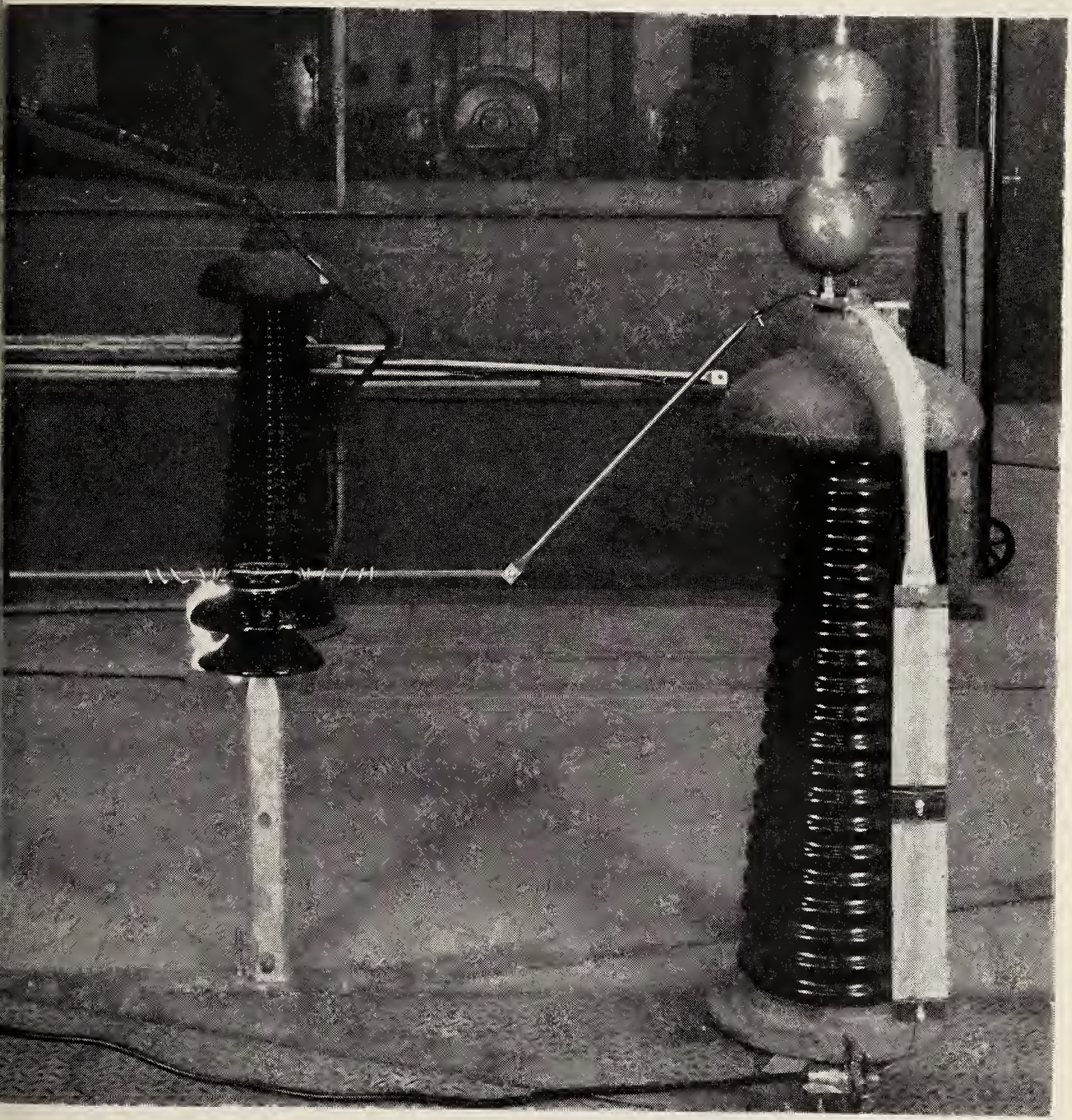


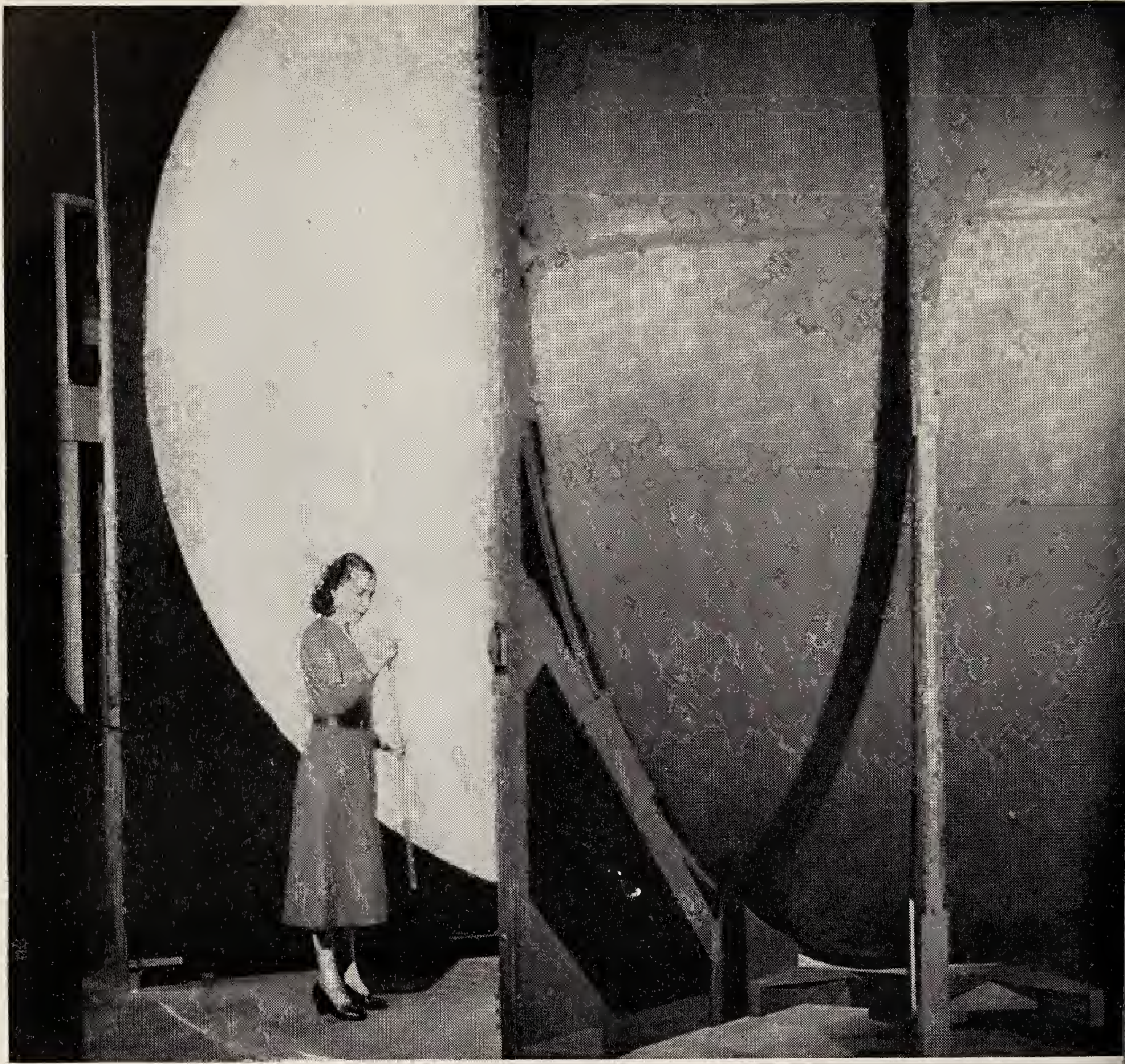
PROVING RINGS. 1. These beautifully-machined devices are used to calibrate the force exerted by testing machines. Developed at the Bureau, they are now made commercially and used in many industries. When force is applied to the poles, the proving ring is distorted, and an indicator registers the distortion. Here a 200,000-pound capacity ring (above) is being calibrated by loading it against three smaller rings. The smaller rings were calibrated by use of dead weights.



LIGHTNING RESISTANCE. 2. Electrical distribution lines are inviting targets for lightning. Porcelain insulators used on these lines must be built to withstand lightning, so that summer storms do not black out whole cities. To test insulators under controlled conditions, the Bureau manufactures lightning. From the huge surge generator, voltages are discharged across a gap at 11 million volts per microsecond.

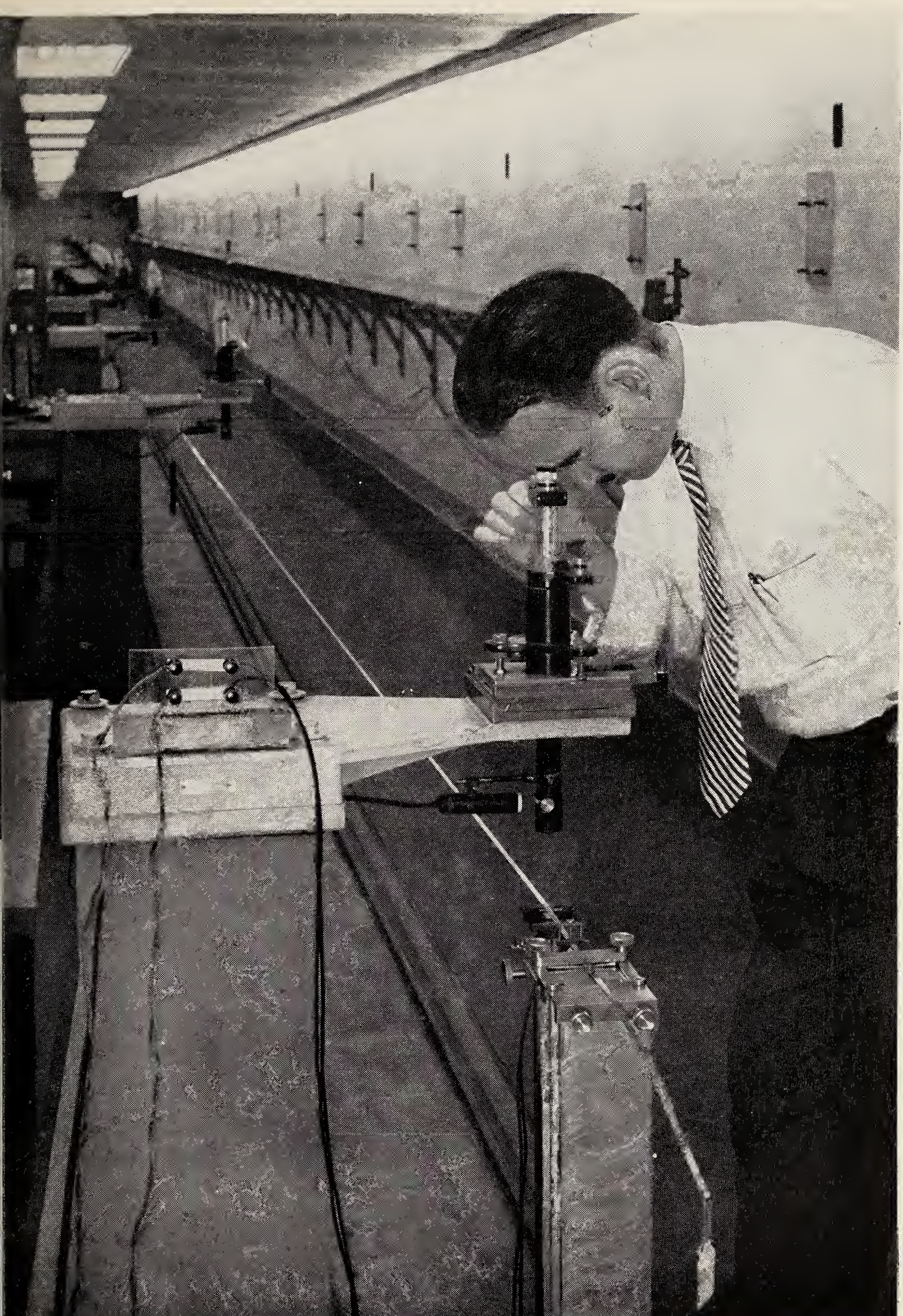
3. In the close-up, the voltage is flashing over the surface of the insulator being tested on the left, indicating that the unit will withstand this potential. At the right is a voltage divider, to which the measuring circuit is connected.

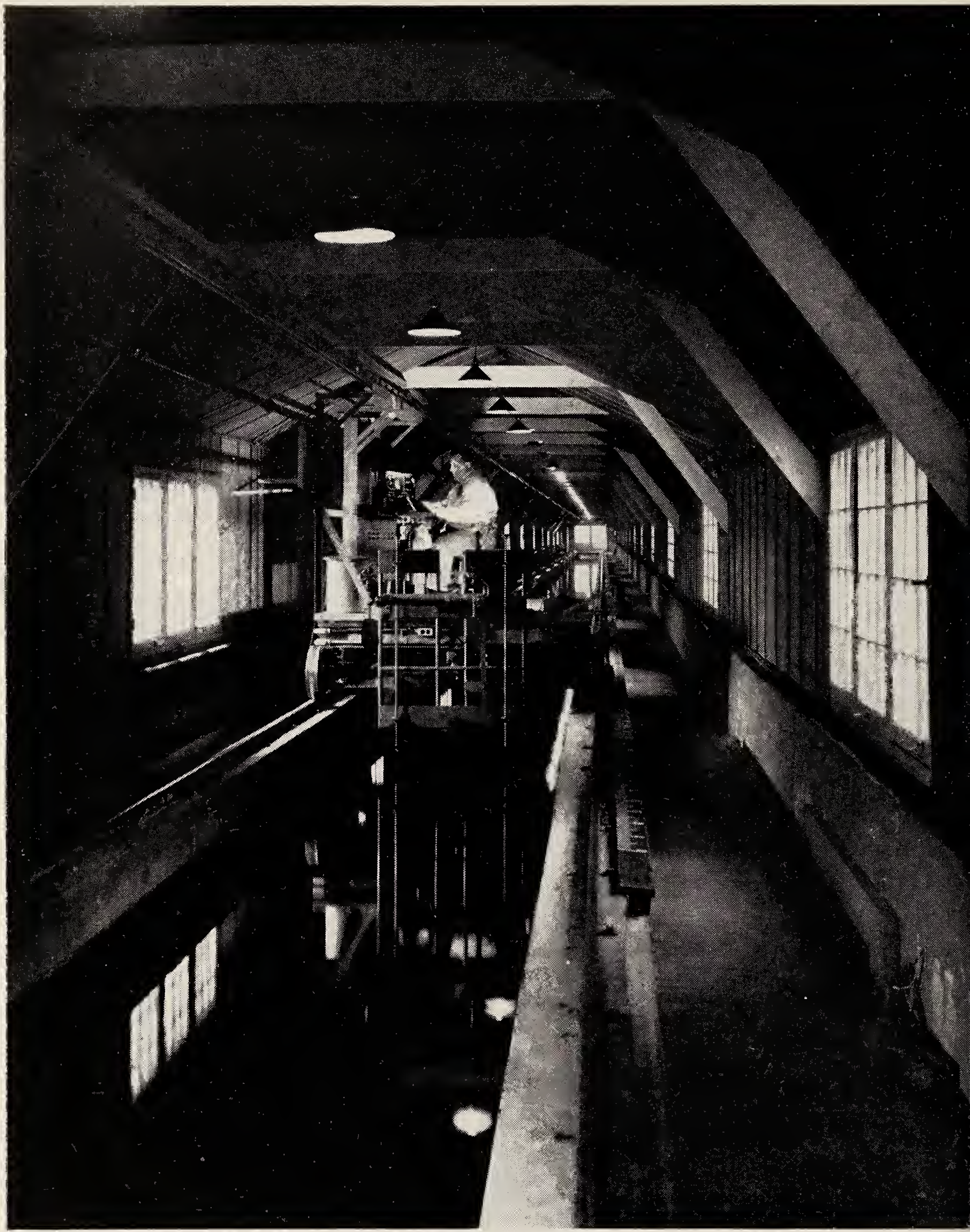




INTEGRATING SPHERE. 4. Measurement of the total light output of incandescent and fluorescent lamps is made with this integrating sphere. When the lighted lamp is enclosed in this sphere, the reflective inside coating diffuses the light so thoroughly and uniformly that its total flux can be measured by a single observation made at any spot on the sphere. This 15-foot sphere, weighing more than a ton, was built to accommodate the largest commercial light sources.

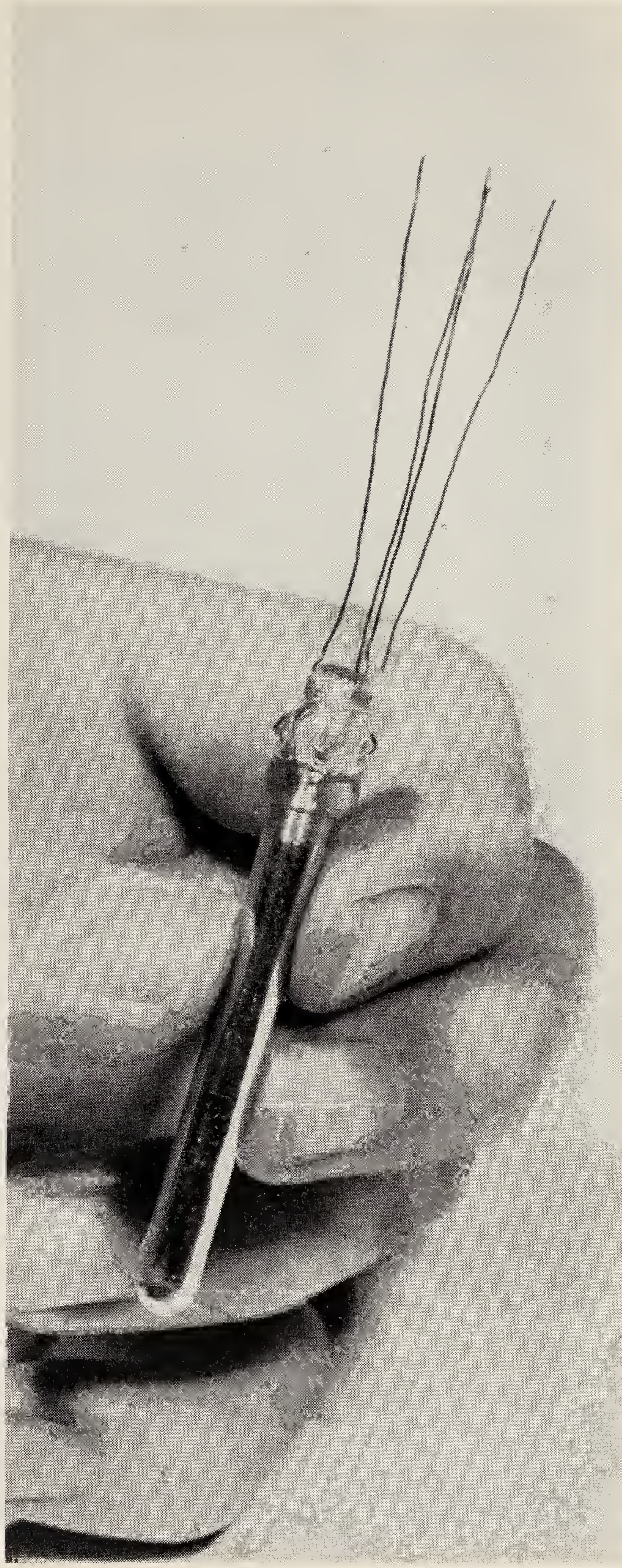
TAPE TUNNEL. 5. In this tunnel, under carefully-controlled conditions, length measurements are made. Here a new N.B.S. method for determining coefficients of expansion is being applied to a surveying tape. Two microscopes are focused on the graduations at each end of the tape. While the temperature of the laboratory is kept constant, the tape is heated by passing a direct current through it.



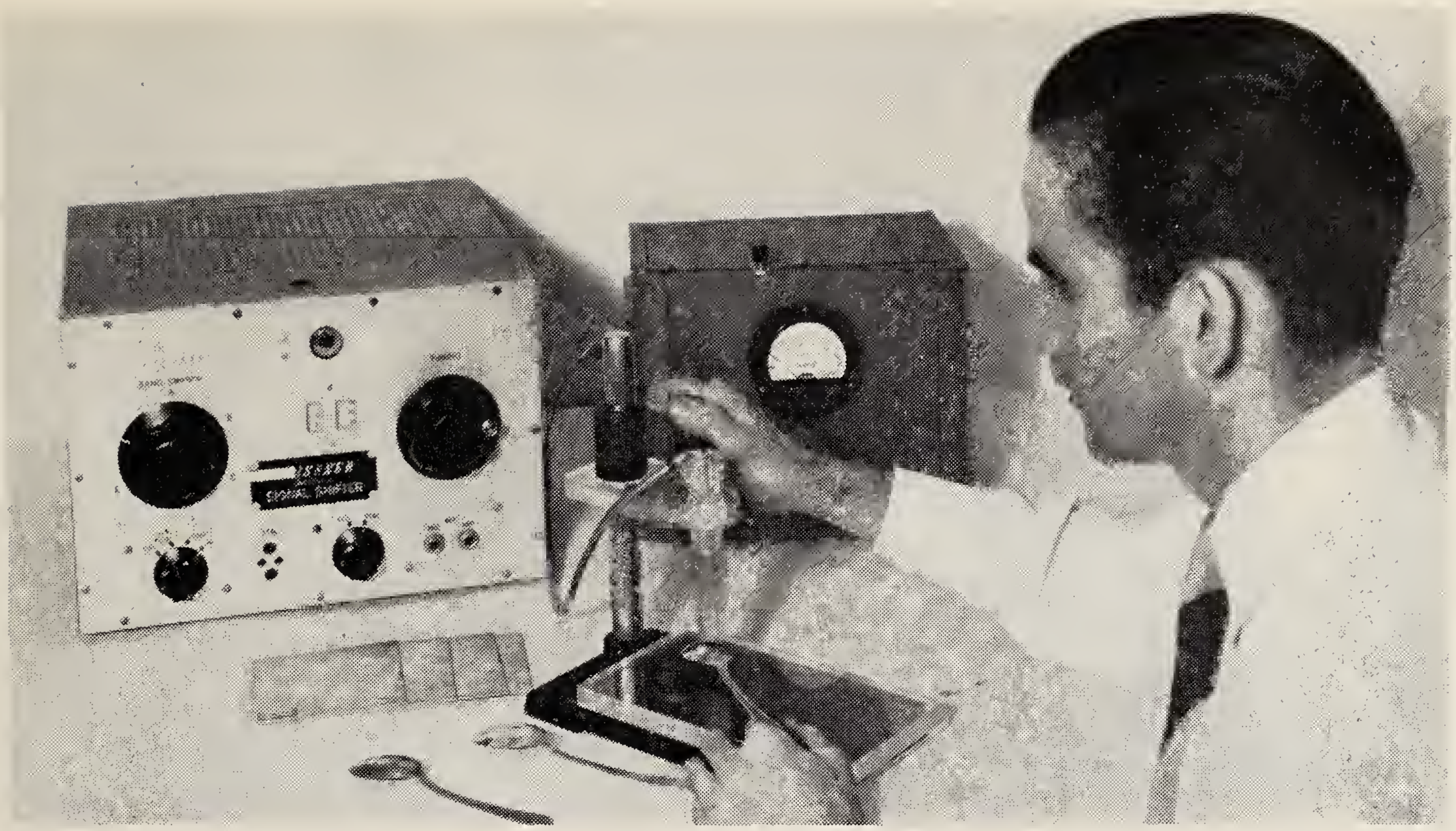


TESTING TANK. 6. Accurate information on stream flow is needed for many purposes. It is gathered at hundreds of stream-gaging stations, where submerged meters record the speed of the water. The accuracy of these meters is tested in this tank at the Bureau, through which they are towed by the moving carriage.

LOW-TEMPERATURE MEASUREMENT. 7. *This tiny capsule resistance thermometer, N.B.S.-developed, will measure temperatures 440 degrees below zero Fahrenheit, only 10 degrees above absolute zero. Thermometers of this type are calibrated against master instruments which, in turn, were calibrated against a standard helium gas thermometer.*

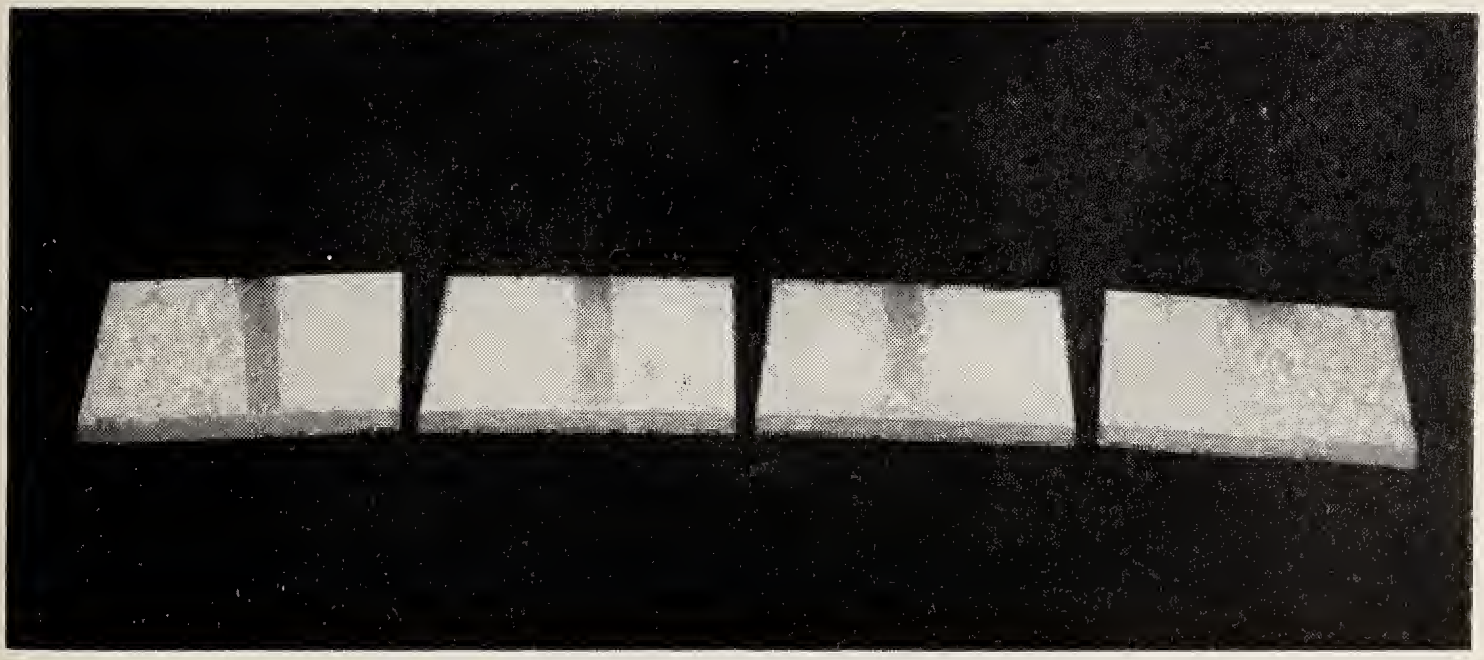


TESTING MERCURY THERMOMETERS. 8. This apparatus was developed for quick, accurate testing of the thousands of mercury-in-glass thermometers inspected at the Bureau each year. Accurately positioned with their bulbs immersed in a temperature-controlled tank, the instruments are read through a scope.

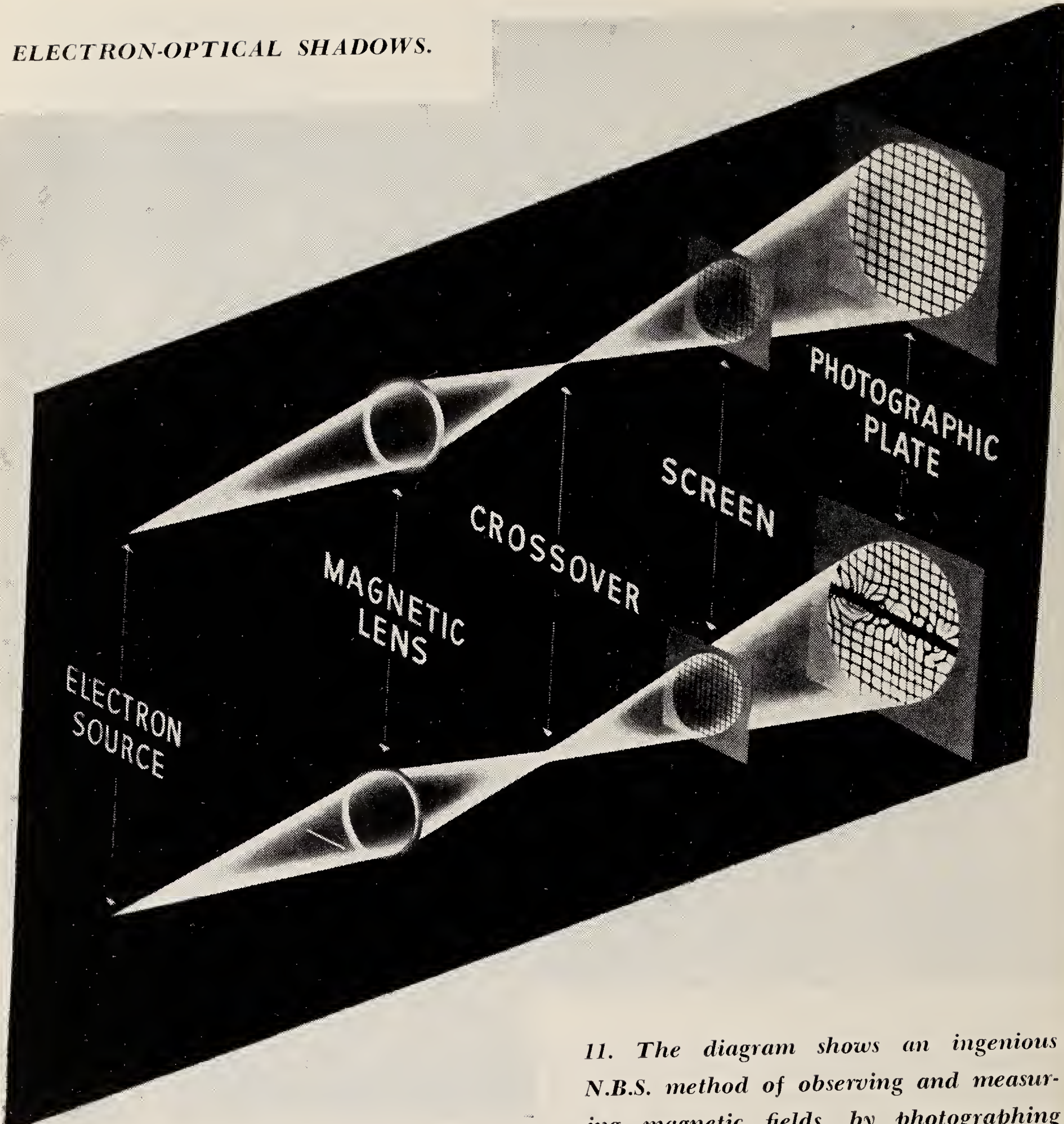


ELECTRONIC THICKNESS GAGE. 9. Measuring the thickness of a metallic coating is no simple problem, at best, and it is more difficult if the coating cannot be penetrated without damaging the object. Shown in the picture is one of several N.B.S.-developed electronic thickness gages, here used to measure the thickness of silver plating.

STANDARDS OF GLOSS. 10. Since glossiness is a quality of many commercial products, standards are needed for process control. The four white surfaces shown here are physical gloss standards, with nominal gloss values, left to right, of 90, 80, 40, and 1. The decreasing surface brightness is shown by the reflected images.



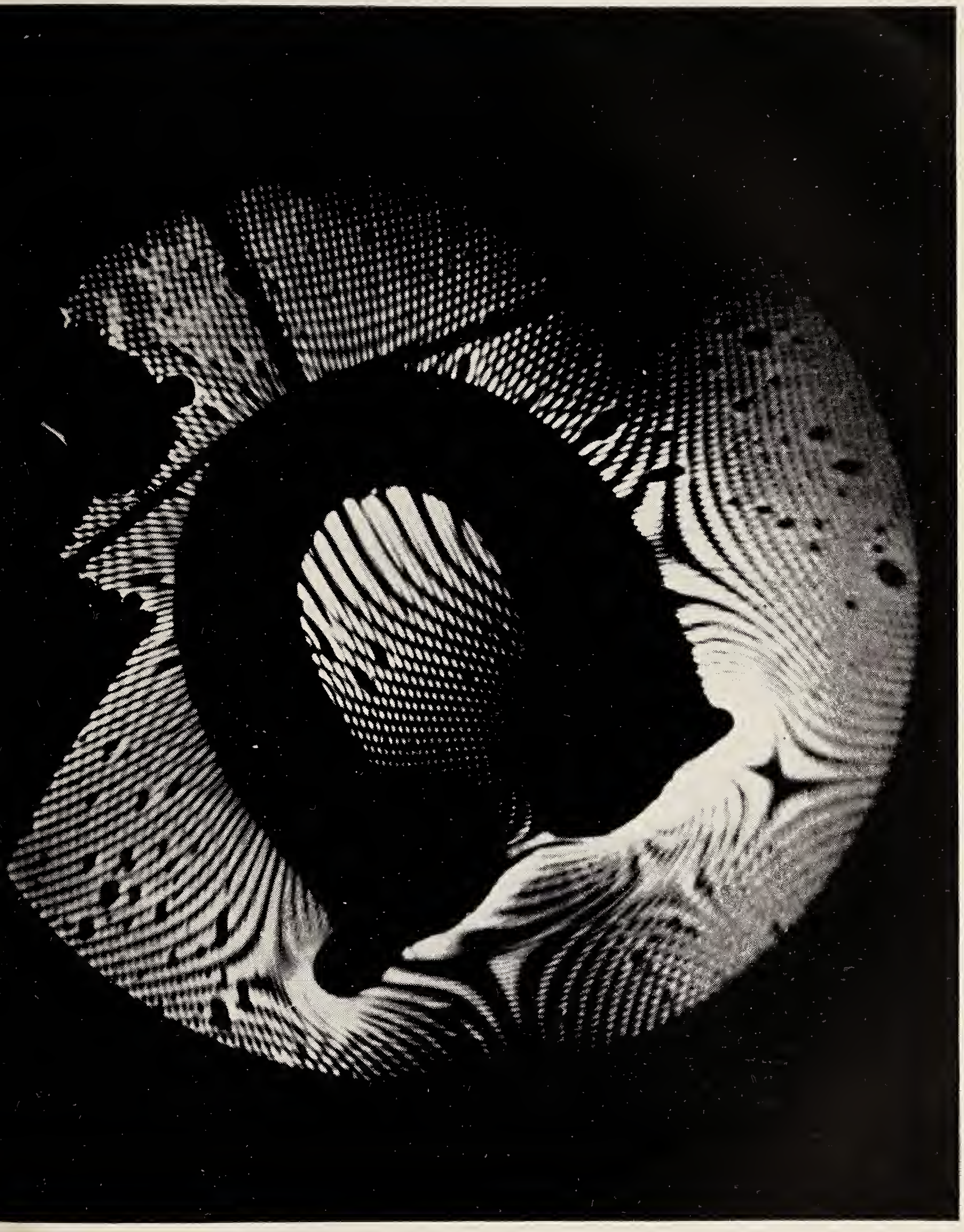
ELECTRON-OPTICAL SHADOWS.

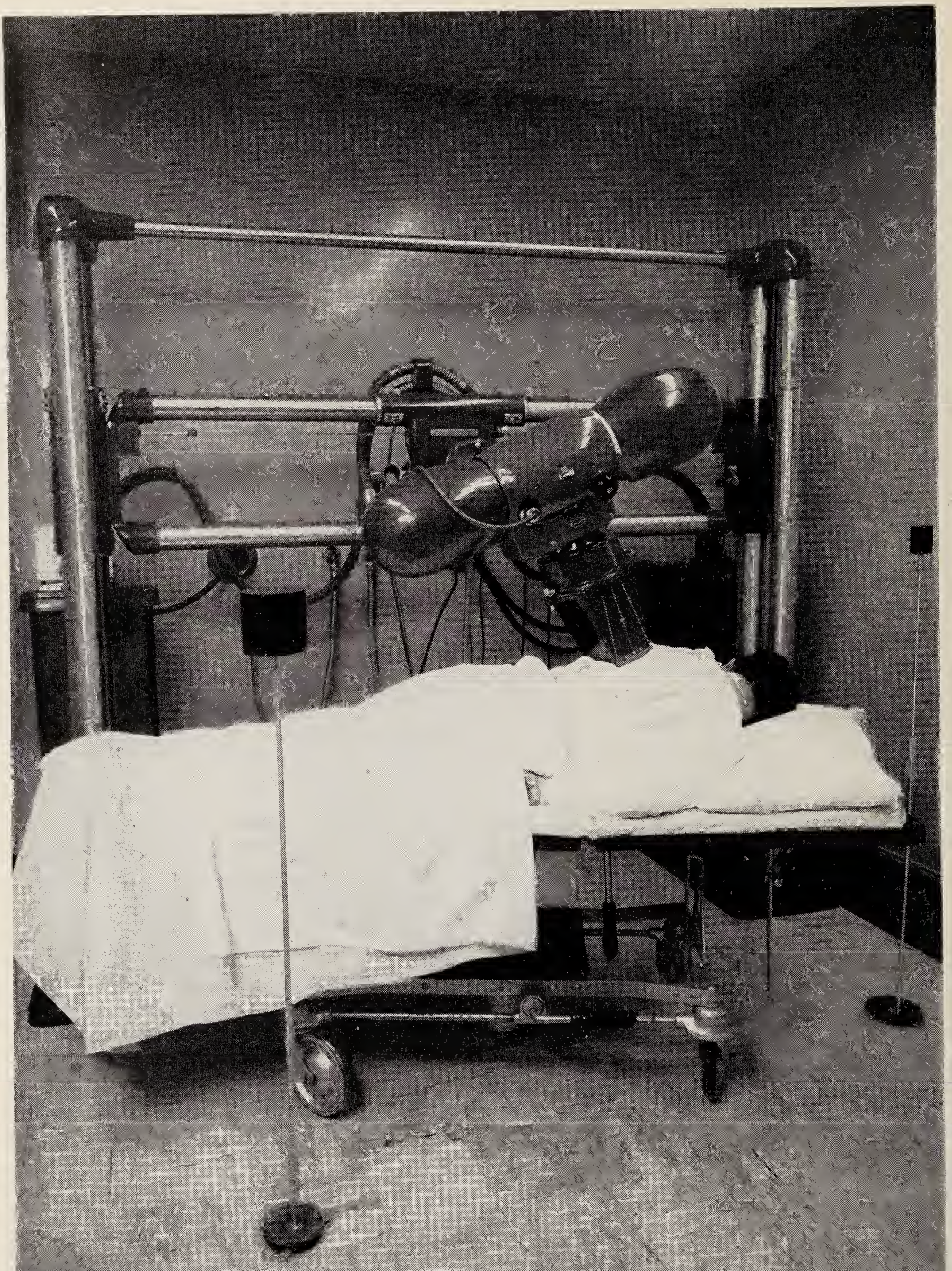


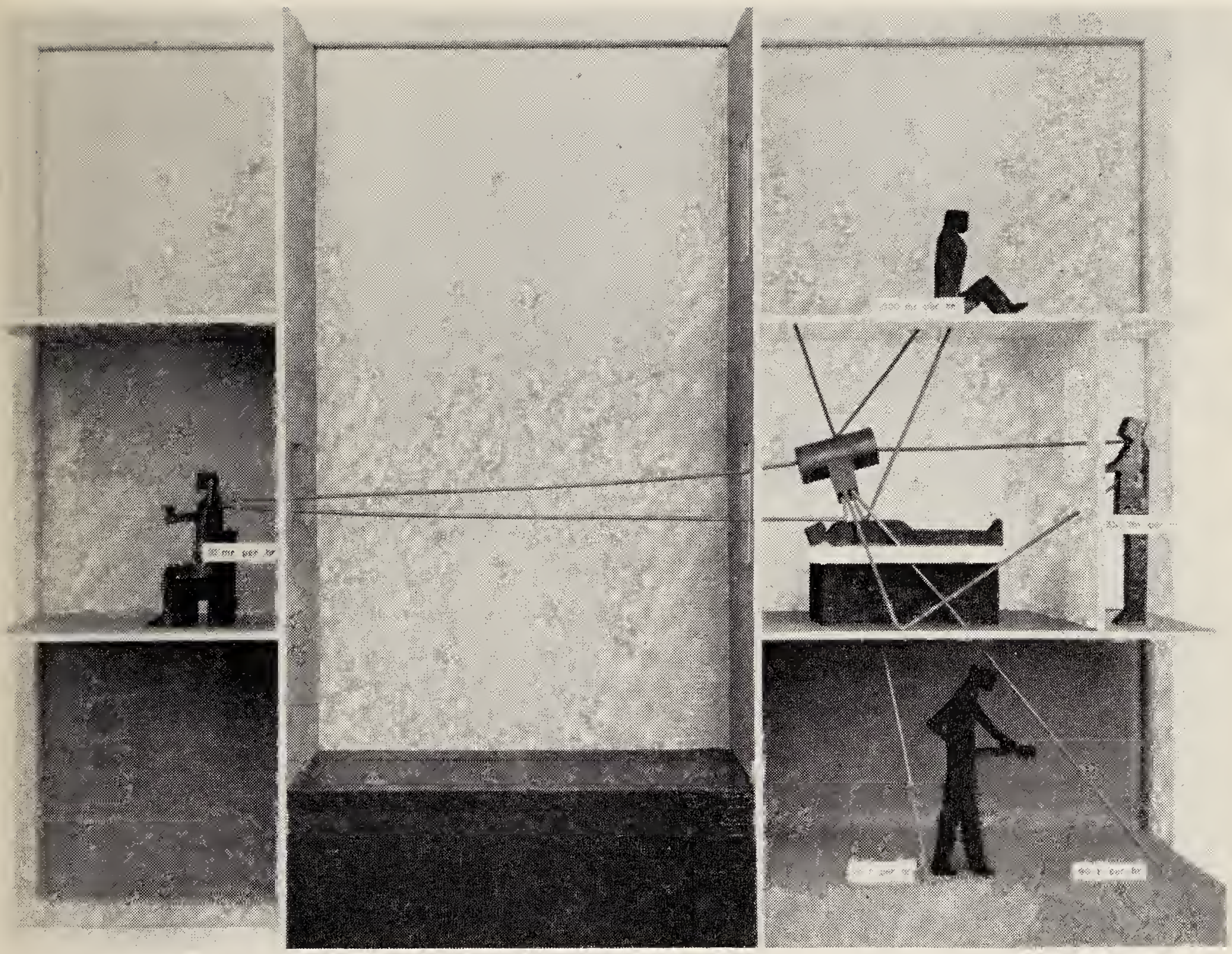
11. The diagram shows an ingenious N.B.S. method of observing and measuring magnetic fields, by photographing them.

The upper portion of the diagram shows an electron beam, focused by a magnetic lens as a glass lens focuses light. The beam passes through a screen, which casts a shadow on the photographic plate. In the lower portion of the diagram, a magnetic recording wire, magnetized in short pulses, has been placed in the beam. Its shadow is cast on the plate, and its magnetic field deflects the passing electrons and distorts the shadow network.

12. The picture on this page is a photograph of the magnetic field of a small horseshoe magnet.

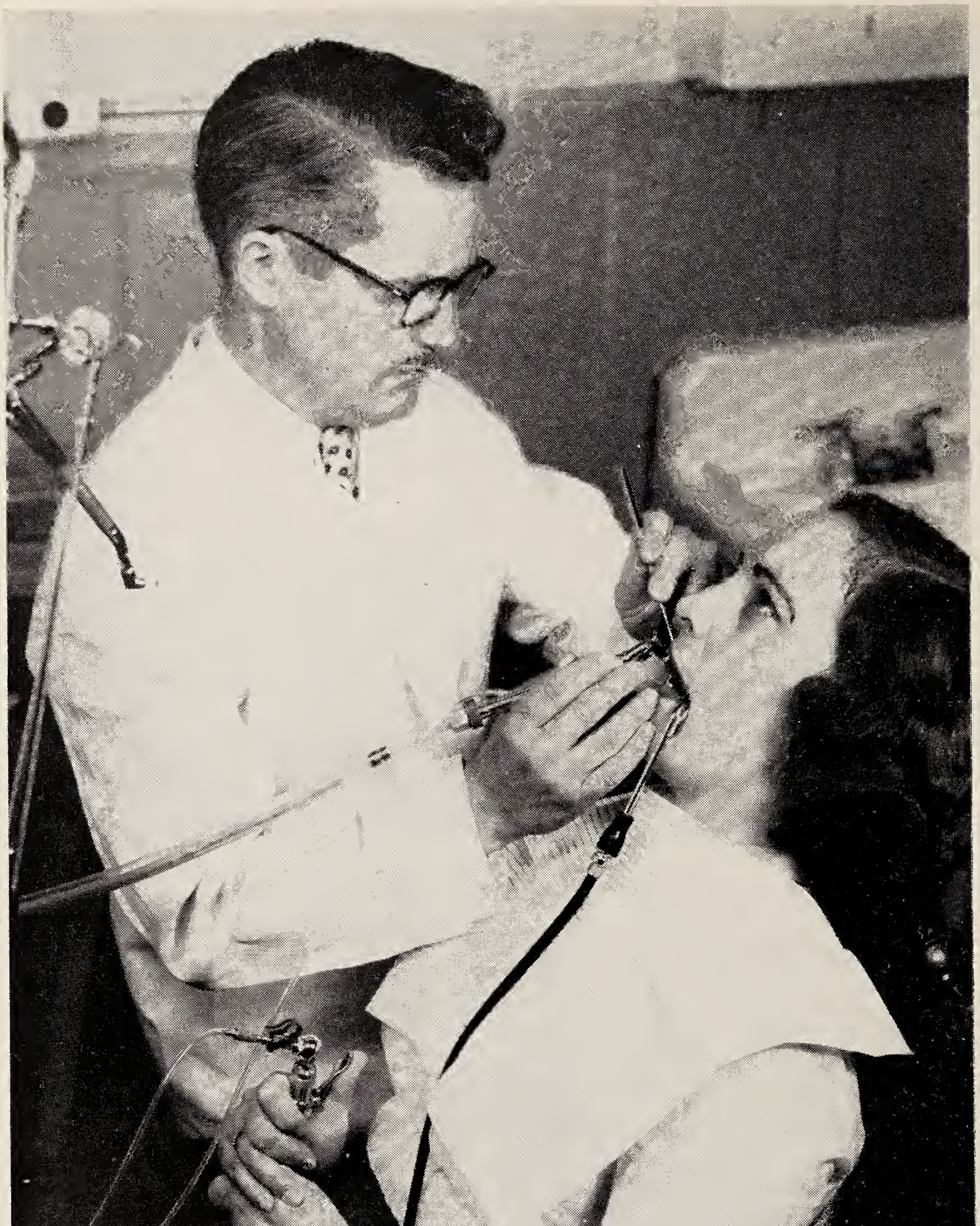


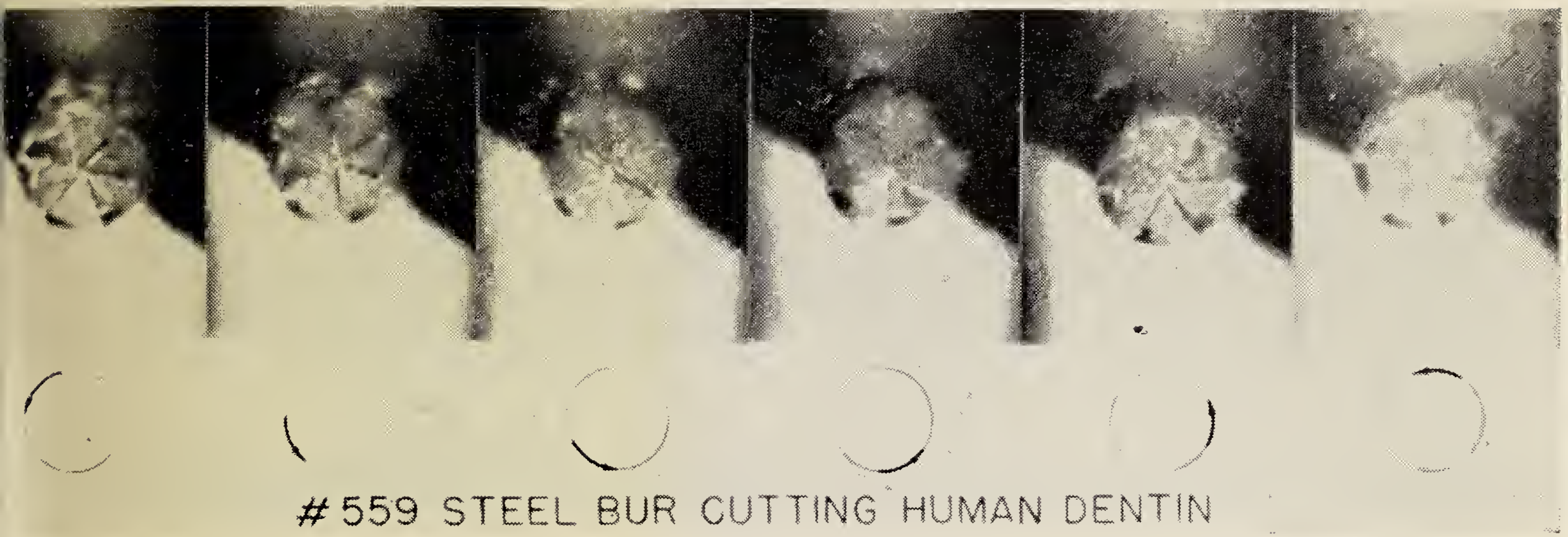




14. Bureau research in radiation has provided information on the shielding required to protect X-ray operators and persons in adjoining rooms. Codes of safe practice are based on these data.

X-RAY PROTECTION. 13. When X-ray equipment is properly used by physicians and dentists, patients are not endangered. But the effects of such radiations are cumulative, and increasing use of X-ray equipment exposes those who work with or near it to serious hazards. Shielding the apparatus itself is important. But, as the ionization chambers, on stands in the picture (left), are detecting, radiations are scattered from the patient.



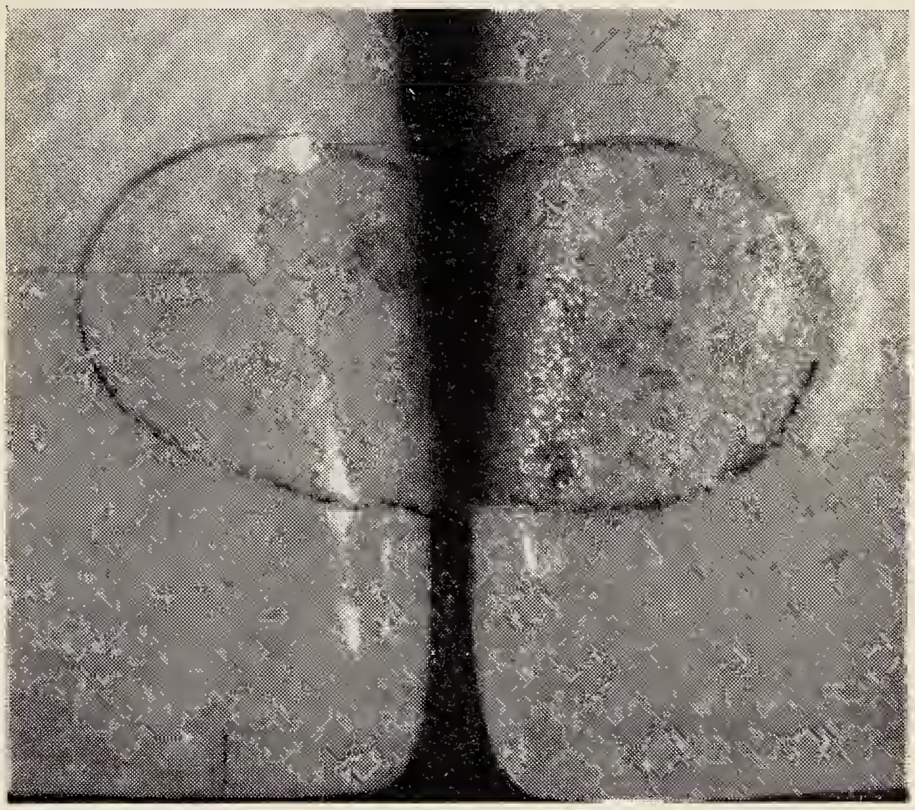


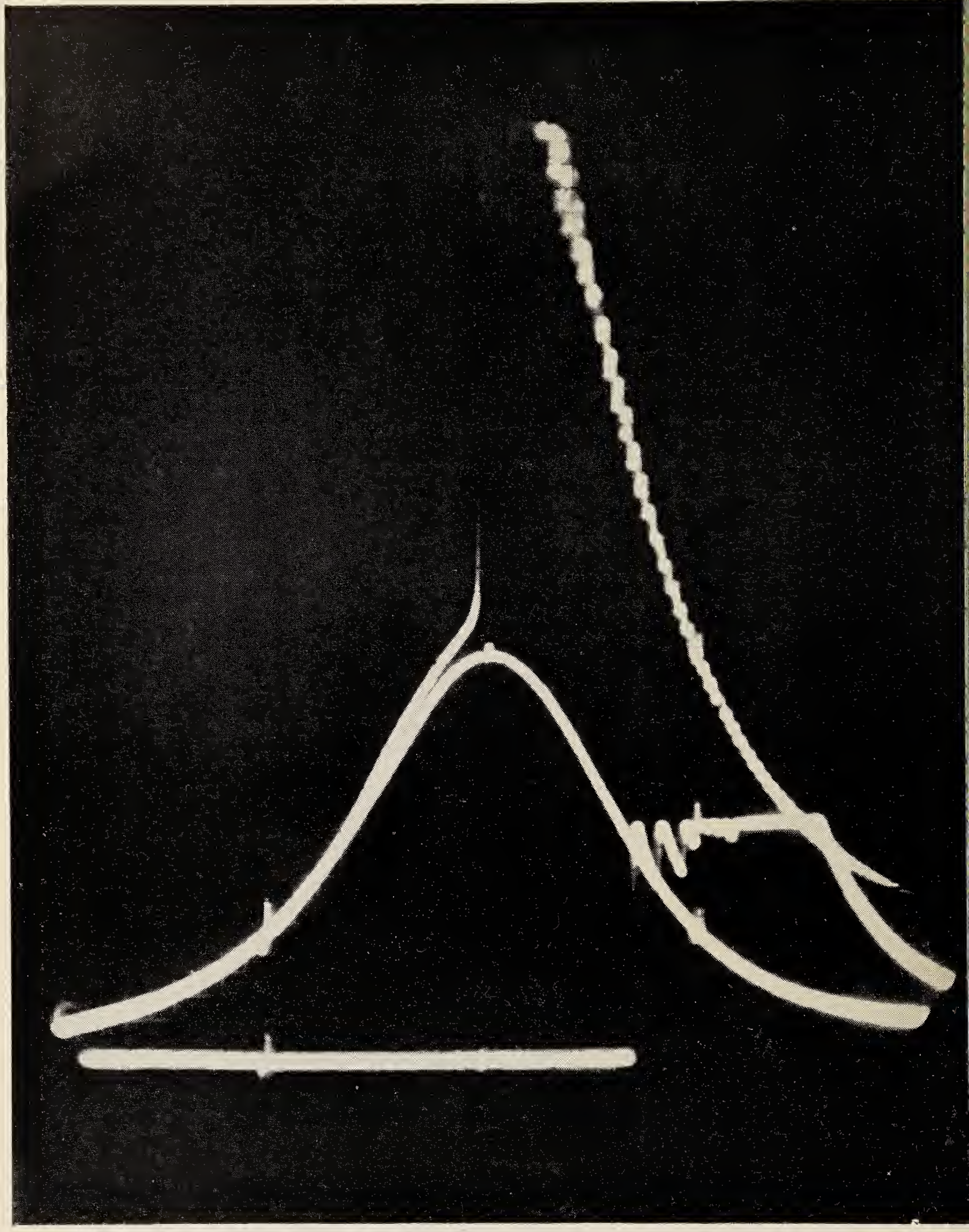
***DENTAL RESEARCH.** The long-standing research partnership of the Bureau and the American Dental Association has done much to make American dentistry the world's best.*

15. On the left is a new hydraulic handpiece, which will soon be ready to replace the present motor, pulley and belt equipment. It operates safely at much higher cutting speeds, with less vibration and heating.

16. The cutting action of burs is studied by high-speed microphotographs. This series of pictures, above, was made while the bur was cutting into a human tooth at 2,500 revolutions per minute at a load of 300 grams.

17. Silicate-cement fillings are observed in actual service. The restoration at the left was made according to an N.B.S.-developed technique and is in excellent condition. The other, made according to the cement manufacturer's instructions, shows erosion and discoloration.





ENGINE KNOCK. 18. This is an oscillogram of engine "knock," made in studies of high compression automobile engines.

Photographs, Courtesy of National Bureau of Standards.

times a day, were as nothing in comparison with those of the wholesaler, who had also to cope with odd-sized barrels and nonstandard bushels, or the research scientist whose intricate calculations involved countless conversions. The problems of the cheese merchant have now been solved by the computing scale. The scientist has resolved his by adopting metric units.

But there is a case for English measure, or, at least, for the ratios of 2, 3 and 4. Indeed, if mathematicians were given the opportunity to turn back the evolutionary clock and redesign the human body, they would be more likely to change the number of fingers to 12 than to revise the proportions of hands, arms and feet.

If man had had twelve fingers, he would have learned to count in units of twelve, and we would have had, in time, a duodecimal system. It is easy enough to construct such a system, adding two symbols after "9" so that the notation "10" means twelve. The mechanics of a duodecimal system are much the same as those of the decimal system. Thus $10 \times 10 = 100$, or 12 groups of 12 units each, or 144 in our system.

It seems cumbersome, of course, because we have only a decimal vocabulary. In a duodecimal system "100" would not be called "one hundred and forty-four" but "one —"—a single word, as simple as "hundred." Persons trained in such a system would find it no more difficult than we find the decimal system.

They would, in fact, find it simpler. One of the difficulties in the decimal system is that 10 is divisible only by 2 and 5. This makes use of fractions awkward. But using a base of 12 instead of ten, the fractions ½, ⅓, ¼, and ⅙ are readily convertible to duodecimal numbers.

When the metric system was first put forward, and on numerous occasions since, a few scholars urged a more drastic reform, substituting a duodecimal system for the decimal system, and redesigning weights and measures accordingly. They have a good case, perhaps, in theory. But no one has ever suggested a plan whereby such an inconceivably vast change in civilization could be brought about.

Here, then, are the roots of the Great Metric Controversy. Measurement and computation had, at last, collided. For persons whose work consisted largely of computation, metric measure was obviously far

more convenient. For others, such as carpenters and stonemasons, the simple fractions of English measure were better.

When the metric system was first introduced, there were even stronger reasons favoring its adoption, which had little to do with the decimal-fraction issue. In every country of the world there was a desperate need for a thorough housecleaning in the weights and measures departments. In past centuries it had been all very well for apothecaries, brewers, vintners, dyers, weavers, potters, printers, surveyors, bakers, corn merchants, ship owners, cordiers, clothiers, and other trades each to have peculiar units, no two in agreement, and for these to differ, sometimes slightly, sometimes drastically, in every city and province.

But the world was changing. Feudal lands and provinces were being unified into national states and empires. Wholesale trade was growing, and a wholesaler was not enthusiastic about the countless errors made by clerks attempting to manipulate thirty or more kinds of measurements, often having identical terminologies. Further, there was no place in the world where a man could put his hand on a physical object and say, with any assurance, that it was an authoritative, reliable fundamental standard of measurement.

So there was need for a system, any system, provided it was designed well enough to command respect, and promulgated by a government which had the power to enforce laws concerning it.

Our English system today is far simpler and far more consistent than in Saxon times. And yet, can you set up conversion tables in our own system of measurements, in which appear the scruple, carat, pica, grain, dram? Can you state the difference between the apothecaries' ounce, the avoirdupois ounce, the Troy ounce, the liquid ounce? Can you state the size of a cranberry barrel?

Such questions would offer not the slightest difficulty to a schoolboy in a metric country. There is one word for length, one for weight or mass, one for capacity. There are standard prefixes for multiples and subdivisions, all decimal. This was one of the tremendous appeals of the metric system to people throughout the world: they could understand it.

That it was born in France was, in part, the result of circumstances. The essentials of the system had been proposed long before. But

France needed a new system as much as any nation, and the French Revolution offered the opportunity, and there were men like Laplace and Lavoisier in France, capable of doing what had to be done.

Talleyrand directed the Royal Academy to begin the great work, and the leading scientists of France were summoned to take part. From the very beginning there was no question as to the principles of design: it would be a unified system, a decimal system, and, if possible, a system in which all units would be derived from a single fundamental standard.

But what was that standard to be? The first one considered was *time,* deriving the unit of length from a pendulum beating seconds. It was rejected, in part because technical problems would not permit sufficient precision, in part because the length of the pendulum would differ from place to place on the earth's surface, and the unit of length would thus not be reproducible everywhere.

They chose instead a classic plan: that the fundamental unit of length be derived from a dimension of the earth. Their new unit, the meter, would be a ten millionth part of a quadrant of the earth's meridian, extending between Dunkerque and Barcelona, north and south of the 45th parallel. This distance was already known, with fair precision, so a provisional meter was adopted at once. A commission was appointed to resurvey the line, using the most accurate instruments available.

It was a remarkable notion, setting a group of scientists to work on a survey in the midst of a revolution! Though they carried impressive documents, local officials found their activities highly suspicious, and they were often denied passage, arrested, detained, questioned, threatened. Their survey markers were white flags. White was the royal color! What could be more damning?

Under such harassing conditions, with daily or weekly interrogation by locally constituted Committees on Un-French Activities, it took ten years to complete the survey, and a number of the original commission members were not among those present when the final flag was planted.

Critics of the metric system have been unkind enough to point out that minor errors were made, so that the meter is not, in fact, a ten

millionth part of the quadrant. In the shadow of the guillotine, it is hardly surprising that someone's hand trembled now and then! But the scientists who made the survey had no illusions on this score. They did not define the meter as a ten millionth of the quadrant, nor did they propose that it be reconstructed, if lost, by repeating the survey. There has been only one definition of the meter: it is a designated metal bar. The original bar was used until the International Meter Bar was constructed in 1875, and it now reposes in the Palace of the Archives at Paris.

A second criticism is that the scientists erred in determining the unit of mass. It was derived from the mass of one cubic centimeter of water at the temperature at which water is most dense, 4 degrees Celsius.

Their measurements were not exact, and they knew that they could not be exact by the use of methods then available. But the unit of mass is not thus defined. It was a physical object, a kilogram weight, which, like the meter bar, was superseded by the international standard constructed after 1875.

All metric units are derived from these two objects, all in decimal relationship.

"Meter" is the term for length; "gram" for weight or mass; "liter" for capacity. The prefixes *deci-*, *centi-*, and *milli-* designate subdivisions of one tenth, one hundredth, and one thousandth. A "centimeter" is one one-hundredth of a meter.

The prefixes *deka-*, *hecto-*, and *kilo-* designate multiples of 10, 100, and 1,000. "Kilometer" is 1,000 meters.

Use of any prefix is optional, depending on the use of the term. For example, it is quite correct to speak of "254 centimeters," though one could also express this same measurement as "2.54 meters." The vocabulary of prefixes has been gradually extended, as the needs of science have increased. The terminology now extends from 10^{-12} to 10^{12}, a range which gives units convenient to both nuclear physicists and astronomers.

Land measure and area can, of course, be expressed in the vocabulary of linear measure: square meter, square kilometer, and so on. But for those who use land measure much of the time, the term *are*

is provided, meaning 100 square meters. The common unit of land measure is the *hectare,* 100 *ares,* which is slightly less than 2½ acres.

The metric system is so logical and reasonable that most people in England or America who consider it for the first time are baffled. Why on earth didn't we adopt it long ago? Why do we adhere to our jumbled system of unrelated units which almost no one can remember and which require time-consuming and cumbersome calculations?

Metric advocates have always been baffled by their opposition, as Congressman Southard was. And, indeed, it is difficult to determine by reading the record just why some of the opponents were opposed. The hearings, of which there have been several, are full of interminable arguments about whether Mexican railroads do or do not use metric units, how a Shanghai merchant measures rice, how many tables in the annual statistics of Borneo are in metric units, and whether the spokesman for the National Association of Manufacturers was appointed by its board of directors or its executive director.

There is also the sociological fact that an American businessman frequently feels impelled to justify his position by discussing everyone's welfare except his own. One must wade through pages of *pro bono publico* testimony to find the single sentence in which he admits that the change would cost him a million dollars.

The issues were clearest when the Great Metric Controversy engaged the attention of Congress in the 1920s. By then the nation's shift from agricultural to industrial production was well advanced; industry's capital investment in equipment was large and growing. Following World War I such new industries as automobile manufacturing had blossomed.

Industries that had favored the change to metric measures in 1902, or hadn't cared, or didn't then exist, were now appalled by the idea of converting. In their early years, it might have made excellent sense. But now they had spent their money on tools, machines, inventories, drawings, and other items in inch measure, and their personnel was accustomed to inch measure. Were the change to be made now, they feared, the cost would be staggering and the period of transition one of prolonged confusion. They sent word to their Congressmen that metric legislation simply must be stopped.

The bill before Congress, like Southard's, would not have compelled them to make the change, its sponsors claimed. But this was a quibble, not an argument. True, no policemen would compel an industry to convert. But economic forces are more powerful than policemen. Had the bill passed, no industry would have had a free choice. The alternative to conversion would have been chaos.

Indeed, if industry, even today, were offered a choice between compulsory change and the 1920 bill, it would probably choose compulsion. If government changed to metric for all official purposes, including purchasing specifications, almost every industry would be forced to adopt metric for some operations. Yet so long as any significant economic group clung to inch measure, all others would have to use it, too. There would be two systems.

Metric advocates have never squarely faced the problems of total conversion, brushing them aside as inconsequential or easily managed. No one has ever made a thorough, realistic study of what the problems are, but they are certainly enormous.

Industry has billions of dollars invested in production machinery, geared to English measure. Blueprints are drawn to English measure. The standard sizes of screws, nuts, bolts, paper, lumber, wire, and thousands of other parts—parts which do not change from year to year—are in English measure. It would not be impossible for an automobile manufacturer, for example, to design and build a new car using metric dimensions. But his changeover would be many times as costly as the usual change from model to model, for it would affect every part and every tool, not just a few. The change would have to be made by every supplier, every subcontractor.

Some other industries would have an even more difficult time. Would anyone propose, for example, that we rip out every plumbing installation? Yet so long as present installations exist, and it may be forever, since systems are repaired and renovated, or partially rather than totally replaced, manufacturers will have to produce repair and replacement parts to inch dimensions. Would the building industry abandon all present sizes of lumber, brick, window frames? Would the railroads change every piece of equipment using inch measure? Would every dimension in every land survey be changed?

These are but a few of the difficulties, and one can argue rather persuasively that the proposition is too staggering to contemplate.

An answer sometimes offered is that physical changes need not be made. Instead, people need only substitute new dimensions, using meters and centimeters in place of feet and inches.

Perhaps this could be done. But it would seem to handicap the metric system from the outset by negating its chief advantage, simplicity. Many of the dimensions of parts and products have been fixed and standardized for convenience. Would a craftsman willingly stop referring to a standard bolt as a "two-inch bolt" and call it a "5.08-centimeter bolt"? Thousands of standard sizes of lumber, pipe, bolts, screws, tools, and so on are described in the language of English measure. As long as these sizes are used, and they would have to continue in use unless the nation were to be rebuilt from the ground up, it is unlikely that a change to metric terminology could be enforced.

The change would make obsolete millions of textbooks and cookbooks, yardsticks, thermometers, scales. In football, what would take the place of the 50-yard line?

"Give him a centimeter and he'll take a kilometer." "A gram of prevention is worth a kilogram of cure."

One afternoon at the 1936 Olympic Games, Jesse Owens said: "This metric system has me all licked. I couldn't tell how far I'd jumped." He had just broken several world's records.

Example can be piled upon example, and difficulty upon difficulty, so the opposition had a strong case when the Great Metric Controversy approached its climax in 1921. But the advocates of change had impressive arguments, too, and both sides were better organized than ever before.

The World Metric Standardization Council presented its case in a 525-page volume. "Keep the World War Won!" was its opening theme. The United States Army had adopted the metric system for wartime use in France. Was this not evidence of the compelling need for a world system? "The German Kaiser would not have dared declare war if America and the British Commonwealth had been standardized on metrics," the Council declared.

But the Council recognized that this debate would not be won or

lost by "rational" arguments alone; it was going to be a test of strength. Most of the thick volume was evidence of strength, a list of the organizations and individuals favoring change. It was an impressive collection: the leading national organizations of scientists, contractors, wholesale and retail grocers, canners, motion-picture producers, clothiers, jewelers, exporters, pharmacists, physicians, educators, chemical, radio and electrical engineers, and many more. There were manufacturers of sugar, paper products, glass, refrigerators, sewing machines, and many other products. The list included several hundred local chambers of commerce and other groups of businessmen, consumers, and professionals.

The opposition had a book, too, published by the National Industrial Conference Board. According to its authors, hardly anyone was in favor of the metric system. The scattering of advocates were "mainly scientists, teachers, and associations formed to spread metric propaganda."

Presumably on advice of public relations counsel, the authors explained their opposition as impartial, unselfish devotion to the public interest. One had to read well into the last chapters to find the statement that the change would, incidentally, cost industry a great sum of money. By an unexplained method, Conference Board economists determined just how much: $200 per employee. It was a nice round figure, which any employer could easily apply to his own payroll.

The hearings were in the Senate this time, and Senator McNary, presiding, complained it was difficult to persuade witnesses to confine themselves to relevant testimony. Emotions were running high, and personal feuds sometimes took precedence over the issues the committee was considering.

In any case, it was not the testimony that shaped the decision. While witnesses put on their show, the lobbyists were busy elsewhere. When it was all over, the metric bill was dead. Across the Atlantic in Parliament, a similar bill was being killed. The Great Metric Controversy was over.

Or was it? Could it come up again, perhaps with a different outcome?

As one reads through the records of the long dispute, one conclusion is inescapable: The opponents of the metric system have not made a

good case against the system itself. There have been religious fanatics and mystics to raise questions of "principle." But the more serious opponents have had a hard time inventing theoretical arguments to support their stand.

Indeed, among the most uncompromising opponents are many who wish the United States had joined hands with France at the very beginning. They acknowledge that the metric system is vastly superior as a system of measurement, and that its advantages once in use would be numerous. But, they say, it's too late now. We are too heavily committed to the system in use.

This is the only real issue: the merits of a superior system versus the costs and difficulties of change. Looking backward today, it is easy to condemn our ancestors for lack of foresight, for preoccupation with their own contemporary problems. The cost of change in 1790 would have been insignificant by comparison with the cost today. It would have been little higher in 1821, when Adams expressed his doubts. In 1866 this was still an agricultural nation. Even in 1902 industry was not so highly standardized and integrated that change would have been unduly burdensome. In 1921 the stakes were higher, but they were not one-fifth as high as the stakes today. At that time the cost of change seemed too staggering to undertake it. But it has increased each year since then.

So, unless one believes that our economy is now mature, nearing its zenith, what will future generations have to say of us? Are we, too, guilty of rejecting change because of its immediate cost, and neglecting the benefits that would accrue to those who follow?

Perhaps so, but it is unlikely that we will do otherwise. At present, pro-metric activity in the United States has virtually ceased. The Metric Association still has an office in Washington, but for years it has not published a leaflet. "The time is not ripe," says its spokesman.

The nations of the British Commonwealth, most of them eager to change to metric units a quarter-century ago, no longer consider the change feasible. The recent report of the special committee appointed by the Board of Trade in England advocated change, but the opposition it aroused was so sharp that the proposal may safely be considered dead.

Internal difficulties are so great that no nation would now consider

change, unless external pressures were overwhelming. Today the volume of trade among the English-speaking and English-measuring nations is greater than their trade with others; and their dominance in world trade is such that they can, in effect, compel the use or acceptance of their units where that seems important. The petroleum industry, for example, is standardized internationally on threads and fittings in inch measure.

Indeed, there is some doubt that the English-speaking nations can soon accomplish a far simpler project: making their own units consistent with each other.

The change needed to bring our units and those of other English-speaking nations into agreement would inconvenience almost no one, certainly not a thousandth as many persons and organizations as would be affected by a change to metric units. Yet there is a real possibility that objections interposed by these few may be enough to block the needed legislation.

7

MEASURING THE INVISIBLE

Measurement is one kind of counting; given a one-foot rule, it is easy to imagine a row of three spanning a distance one could call "three feet."

Some kinds of measurement are counting, that is: length, weight, volume—these terms suggest tangible objects: measuring-sticks, pieces of metal, hollow vessels.

Time can be counted, by thrusting a stick into the ground, plotting the tip of its shadow as the sun crosses the sky, and dividing the arc into linear units.

Man was aware of length, volume, weight and time long before he could count or measure them. Animals cannot measure (even the inchworm!) but they make quantitative judgment, as a bird does in building its nest or a panther in judging its leap.

Like animals, early man was also aware of other phenomena which were variable, and he could sense the variations; but he could not measure them, because there was no way of dividing them into units, or adding units. The air was dry or humid, the day bright or dim, noises loud or soft, a cry high or low in pitch. He was aware and interested, and he coined descriptive words for the variations.

Long years passed before he began to find the means of measuring such phenomena. But even then his curiosity was only sharpened by a question: "What is this? what am I measuring?"

Man was keenly aware of temperature, for heat and cold meant

life or death to him. He fled south before the advancing glaciers, fled before grass and forest fires. In time he learned to tame fire and use it against the cold. Temperature is a critical factor in man's environment. The known scale of temperatures is broader than a hundred million degrees, but on this scale, the range within which man can survive is a tiny band.

Our bodies are highly sensitive to temperature. Seated indoors, we may find 2 degrees the difference between comfort and discomfort. Few people enjoy swimming in water below 65 degrees Fahrenheit, but at 80 degrees it is too warm. A mother can sense a child's fever by touching its skin, even if the fever is no more than a degree above normal. Cooks once judged oven temperatures by thrusting a hand inside. Trappers in the north woods are expert judges of cold. We cannot stand tap water much hotter than 140 degrees Fahrenheit. It is painful to hold an ice cube tightly for more than a few seconds.

How hot is a fire? How cold was it last night?

Early man may have had some crude ways of "measuring." A very hot fire kept him several paces away; closer he felt pain. If it were less hot, he could squat comfortably beside it. It is said that a tribe of aborigines in Australia still has an odd unit of cold: the dog. On cool nights, members of this tribe use domesticated dogs in place of blankets. Thus a moderately cold night is a "two-dog night," while a "six-dog night" is icy.

Differences in temperature can be graded without measuring units. In cool air, exhaled breath condenses; when it becomes still colder, water freezes; well below freezing spittle crackles in mid-air. On a heated rock, a pool of water steams; hotter still and it boils; still hotter and drops will sizzle or dance.

Man learned to use fire to roast meat and cook grain, and then to fire pottery. He learned to build hotter and hotter fires. Water boils at 212 degrees Fahrenheit; Neolithic pottery was fired at 500 degrees. Hotter fires were made in furnaces, with bellows to pump in air. In his furnaces man learned to make bronze and glass. He had ways of telling when a fire was hot enough, or too hot, for his purposes, and, no doubt, had words to describe these points of temperature, but this was not measurement.

What was heat, or temperature? Man knew no way to add or sub-

tract temperature. Why did the ashes of the fire soon cool, while the adjacent rocks remained hot? It was puzzling that one end of a stick burned while the other remained cool; a bar of metal would not burn, but if one end were heated the other soon became hot.

The Greeks had a clue to temperature measurement: They knew that air expands when heated, and they applied the principle mechanically. But they did not devise measuring instruments.

Galileo was the first, or among the first, to attempt it, in 1593, measuring temperature on a scale of graduated units, setting up a one-to-one relationship between hotness and linear units. He had a bulb of air. When it was heated, the expanding air forced liquid down a graduated glass tube immersed in an open vessel of liquid. It was a faulty instrument, the liquid level responding to changes in atmospheric pressure, too. But it was a beginning.

In the 17th century sealed thermometers were made, using alcohol as the liquid. Mercury was substituted for alcohol about 1660. Then, in 1714, Gabriel Daniel Fahrenheit, a German instrument maker, devised his mercury thermometer.

In experiments with alcohol thermometers, Fahrenheit observed that pure ice melting in the presence of pure water always yielded the same temperature reading. He wanted to investigate the boiling point of water, to learn whether it had similar constancy, but he could not do this with alcohol thermometers, since alcohol boils at a lower temperature than water. He chose mercury as the most suitable liquid.

Mercury, like other substances, expands when heated, contracts when cooled. Fahrenheit's thermometer had a sealed bulb of mercury connected with a closed glass tube. When the mercury was heated, a column of the liquid rose in the tube, up to a certain point. Here was an instrument, a convenient way of observing a natural phenomenon. But this was still not measurement. That came with the next step, applying an arbitrary scale of units. Fahrenheit subdivided the glass tube, as if it were a yardstick, into linear units.

He could have marked off the tube in any regular divisions and assigned numerical values as he chose, for the scale was necessarily arbitrary. But he had in mind one important principle: *reproducibility.*

Though the scale was arbitrary, it might be possible to arrange matters so that other thermometers could be fabricated and subdivided in the same way, so all would give the same readings under the same conditions. To give his scale lasting value, he sought two reference points in nature, two temperature levels which could be duplicated precisely by any experimenter, so that thermometers could be calibrated without reference to a master instrument.

Using both alcohol and mercury thermometers, and repeating his experiments many times, he found the temperature of a mixture of ice and salt always the same. This was the lowest temperature he could produce under standard conditions, so he called it zero. A higher point was also necessary, for differences in the internal dimensions of thermometers would cause variations in the linear distances the mercury columns would rise and fall. He had not yet determined the constancy of the boiling point of water. The melting point of ice was too close to his zero.

Several years earlier, Isaac Newton had experimented with oil-filled thermometers. They were not very successful; but Newton had used a 12-degree temperature scale, using as his upper fixed point the temperature of the human body. Fahrenheit accepted Newton's idea that body temperature, in a healthy person, was unvarying, a belief soon to be proved faulty. He also, at first, accepted Newton's 12-degree scale, subdividing the column between the two fixed points into 12 linear units, or degrees. By linear measurement, the divisions were extended below and above the fixed points.

The 12-degree scale was not convenient to use, however, for an instrument as sensitive as the mercury thermometer. Rather than use fractions, Fahrenheit began subdividing the 12 degrees: first into 24, then 48, finally into 96 degrees.

Using this scale, he determined the freezing point of water was 32 degrees, and the boiling point 212 degrees. These are the values we accept today. But on this scale average body temperature is 98.6 degrees, not 96. What happened? Where was the error in Fahrenheit's work?

There was some error in his instruments. When the glass tubes of these early thermometers were sealed, the glass was not annealed. A

thermometer thus made changes over a period of time. If a fixed point is marked by experiment when the instrument is new, later observations will show some error.

Fahrenheit wanted to have his two fixed points as far apart as possible. Once he had confirmed that the boiling point of water is constant, he adopted it as his upper fixed point, abandoning body temperature for the purpose. Finally, his instruments were the most sensitive yet made, and he soon discovered that body temperature is not constant, even in a healthy individual. It may vary by a degree or two in the course of a day. It was therefore not a suitable fixed point.

But he did not abandon his original plan of subdividing and numbering degrees, So it is that we have the rather awkard Fahrenheit scale, on which 32 degrees corresponds to the zero point on the centigrade or Celsius scale.

Fahrenheit designed and built a remarkably useful instrument, opening up many new possibilities of scientific investigation. But he was never able to discover or explain just what it was his instrument measured!

Temperature? Of course there is such a phenomenon; anyone can feel it. By experiments one can demonstrate that the expansion of mercury is a result of warming: it always expands when warmed, always contracts when cooled.

But still, what is temperature? Is it a quantity? If so, does the expansion of mercury from 10 degrees to 15 degrees on the scale indicate a rise in temperature equal to the rise from 110 to 115 degrees?

Other experimenters were studying the phenomenon. In 1731 a French scientist, Réaumur, introduced a temperature scale with an interval of 80 degrees between boiling and freezing. A Swedish astronomer, Celsius, first proposed a decimal division of the scale, an interval of 100 degrees between these same two points. In the original Celsius scale, boiling point was zero, freezing point 100. Ultimately inverted, it became what was known for many years as the Centigrade temperature scale, recently officially rechristened "Celsius." The term "Centigrade" therefore is gradually being replaced.

Eighteenth century experimenters seem to have spent much of their

time inventing new ways of subdividing the column; before they desisted, nineteen different scales were in use. Of these, only three survive: our Fahrenheit scale; the Réaumur, still known in parts of Europe; and the Celsius, used in almost all metric-measuring countries and generally for scientific work.

Equipped with better instruments, scientists made many new observations, but with results more puzzling than illuminating.

One might prepare two thermometers, for example, filling the first with mercury, the second with a different liquid. Both were calibrated so their readings coincided at the two fixed points, boiling and freezing. But at intermediate points their readings might differ! Thus it seemed that while liquids expand when warmed, they do not behave according to a simple general law, expanding at constant rates as temperature rises. And so, since liquid-in-glass thermometers were the only measuring instruments known, how could any one liquid, such as mercury, be accepted as a reliable means of measuring?

Using a Fahrenheit thermometer, a piece of ice might show a reading of 15 degrees. Now if the ice were warmed, the apparent temperature would rise gradually to 32 degrees. But there it would stop, despite further warming, until the ice had melted! Then the gradual rise would resume, up to 212 degrees, the boiling point. Again the column of mercury would halt, despite intensive heating of the water, while the water boiled away, turning to steam.

Could temperatures be added and subtracted?

If equal quantities of water at different temperatures were mixed, the temperature of the mixture appeared to be the average of the two.

On the other hand, if two pieces of different metals, of equal weight, were warmed to the same temperature, and each placed in a separate beaker of cooler water, thermometers placed in the beakers would rise—but not to the same points! Or if these pieces of different metals were heated and placed on cakes of ice, they would melt different quantities of ice.

Such evidence ran counter to the theory that the temperature of an object or substance indicated its heat content—or the notion that temperature and heat were identical. But not until the middle of the eighteenth century did a Scotsman, Joseph Black, make the clear

distinction between the two: "the quantity of heat in different bodies" and "its general strength or intensity."

What was heat, then? Obviously something quite unlike temperature; to warm a quantity of air takes less than one three-thousandth as much heat as required to raise the temperature of an equal volume of water the same number of degrees, a fact which makes steam and hot water heating systems practical.

It became convenient to think of heat as a *substance*, perhaps an invisible liquid, which flowed from one material to another. Indeed, there was experimental evidence to support this idea: when wood burns, the resulting ashes weigh less than the original wood; and when certain metals are heated, they are reduced to powder which weighs more than the original substance. When it was demonstrated conclusively that no increase in weight occurred when substances were heated without chemical change, the "calorists"—exponents of the heat-substance theory—simply replied that the invisible fluid must be weightless!

Among those who experimented with heat and temperature was Benjamin Franklin. Though a calorist, he helped to resolve one of the many puzzles: if a piece of wood and a piece of iron are heated to, perhaps, 120 degrees Fahrenheit, the iron will feel hotter than the wood when touched. If both are chilled to the same temperature, the iron feels colder to the touch.

Franklin demonstrated that substances differ in the ease with which they conduct heat. He coated bars of different metals with beeswax, and immersed one end of each bar in a hot liquid. Heat, traveling along each bar, melted the wax. The rate of progress of the melting differed from bar to bar; and at the end of the experiment, different lengths of the bars had been exposed by melting. Three decades later Joseph Fourier formulated the definition of thermal conductivity, describing how the conductivity of a substance could be determined. (Silver, for example, has a conductivity about 50 times that of mercury.)

Black's concept of "capacity for heat" has become known as the *specific heat* of a substance. The unit of heat in the metric system is the calorie, the amount of heat which will raise one gram of water

through one degree Celsius; the British thermal unit (Btu) is the heat required to raise one pound of water through 1 degree Fahrenheit. Specific heat of a substance is a ratio: to raise the temperature of copper requires about one-eleventh as many calories as to raise an equal weight of water the same number of degrees. The specific heat of copper is 0.093 (water being taken as 1.000).

Innumerable observations and experiments added to our knowledge of heat, but often led to wrong theoretical conclusions. Many experimenters had been baffled by the behavior of the thermometer during changes of state. Fahrenheit, for example, managed to confuse himself by the results of this experiment. He cooled water to several degrees below the freezing point, and it remained a liquid until it was slightly agitated. Then a part of the water turned to ice, while the temperature of the mixture *rose to the freezing point.*

Joseph Black attacked this problem of transformations between solid, liquid, and gaseous states. In a simple experiment, he defined the phenomenon he called *latent heat.* He placed a lump of ice in an equal quantity of water heated to 80 degrees Celsius. When the ice had melted, the liquid was at the freezing point, the original temperature of the ice! Evidently there had occurred a large absorption of heat in the process of melting, with no rise in temperature. A new idea followed logically: that there is a large evolvement of heat in the process of freezing. By Black's method, the heat required to melt ice was found to be 80 calories per gram.

One of the vital clues to the nature of heat had been available for centuries: the fact that heat is produced by energy. Savages used friction to start fires. Hammers and saws and files had long been in use, and workmen knew their tools became hot. A primitive form of steam engine was known in the early eighteenth century, a device which turned heat into energy.

In 1842 a little-known German doctor, J. R. Mayer, wrote a paper which described the principle of the conservation of energy: that energy cannot be annihilated, but can only change its form. He cited numerous examples, such as those above, of the conversion of energy to heat, heat to energy. But he had difficulty in finding someone willing to print his paper, and when it appeared he was ridiculed.

But not for long. The pieces were being fitted together. Joule reinforced Mayer's assertions, and demonstrated the mechanical equivalent of heat. Watt's improvement of the steam engine provided an ideal device for experimentation. There had, in fact, been many speculations which came close to the mark. Galileo had suggested that heat was the motion of "corpuscles." Much closer were the observations of Benjamin Thompson, born in Massachusetts before the Revolution, an officer in the British Army, who became Count Rumford through services in Bavaria.

Among these services was making cannon for the Bavarian army. His boring machine was driven by a horse walking on a treadmill, and Rumford became curious about the large amount of heat produced by action of the boring tool against the brass cannon block.

According to caloric theory, this heat was the result of the boring action which squeezed caloric fluid from the metal. If this were so, then there should be much less "caloric" in the shavings—and a little experimenting proved that couldn't be true.

But if the heat had not somehow come out of the metal, where did it come from? Rumford speculated about this heat, which "might be produced, by proper mechanical contrivance, merely by the strength of a horse, without either fire, light, combustion, or chemical decomposition. . . . But no circumstances can be imagined in which this method of procuring Heat would not be disadvantageous; for more Heat might be obtained by using the fodder necessary for the support of the horse as a fuel."

In a modern laboratory, it would take a high school student only a short time to disprove some of the notions which for years were held by able scientists of earlier days. But the student would be taking advantage of knowledge they did not yet have, and using his instruments with a confidence they could not place in theirs.

Early research into the measurement of heat and temperature was, at the same time, an inquiry into their nature; and measuring instruments, such as the thermometer, had unknown characteristics so long as it was not certain what caused their behavior. Suppose, for example, that in successive experiments readings were obtained which were not in accord with calorist theory. This *might* mean the theory was wrong;

it *might* mean the instruments were faulty; or there *might* be some other explanation.

Was there a caloric fluid, and did it have weight? If an experimenter weighed a block of metal when it was cold, then again when it was hot, and found no difference, could it be, perhaps, that his scales were not sufficiently sensitive? Another experimenter reported that on *his* scales the heated block weighed more. Did it, or did the heat of the block warm the pan and beam of the scales, causing them to expand and thus displace the scales' center of gravity?

The mercury thermometer was improved, but it had limitations. For example, it had a limited range, since mercury freezes at −40 degrees Fahrenheit. Gas thermometers were introduced about the middle of the 19th century. The laws of gas expansion were found to be simpler than those governing liquids, though mercury thermometers were found to agree more closely with gas thermometers than did those using any other liquid. Gas thermometers also extended the range of temperature measurement.

The answer to the question, "What is heat?", led to the design of a new temperature scale. On Fahrenheit's scale, the zero had an arbitrary meaning; it did not signify the *absence* of temperature. He knew lower temperatures occurred in nature. A point such as −10 degrees did not represent a negative quantity. He could, with equal reason, have called it plus 90 degrees, adding 100 to all of the numbers on his scale.

But now there was a new concept, that heat is energy. When heat is applied to a body, it increases the energy of that body; if no change is detected in its kinetic or potential energy, the energy must have come from the motion of its molecules. Heat is a form of energy which in gases is practically the kinetic energy of the molecules, and in solids and liquids also includes the potential energy due to expansion. Changes in temperature signify changes in molecular energy.

So there could now be a meaningful zero, existing theoretically if not actually attainable: *absolute zero,* the temperature of a body in which there is no molecular energy.

The new theoretical thermodynamic temperature scale was based in part on the work of Lord Kelvin, who resolved established laws and experimental evidence into a formula, a definition of temperature

independent of the physical properties of a measuring medium such as mercury.

The zero point on his scale is fixed by scientific formulae, not arbitrarily. But otherwise Kelvin had the same choice as Fahrenheit: he could subdivide his scale and assign numerical values as he pleased.

Kelvin was an ardent supporter of the metric system. In later years he appeared before a committee of the United States Senate to present the case for its adoption here. He knew the Centigrade-Celsius scale would remain in use for all ordinary purposes. So he decided that on the new absolute scale there should also be a 100-degree interval between the freezing and boiling points of water. On the Celsius scale, absolute zero is −273.15 degrees. On the Kelvin scale, the freezing point of water is 273.15 degrees, the boiling point 373.15 degrees.

The new laws of thermodynamics, establishing heat-energy relationships, had enormous significance for science, engineering, and industry, for "energy" meant all kinds of energy: mechanical, electrical, radiant, chemical. The fixing of standards became essential, as well as the provision of instruments reliably based upon those standards.

Yet in the United States in 1903, when the National Bureau of Standards accepted its first batch of mercury thermometers for testing, the condition of even these simplest of instruments was deplorable. Some manufacturers seemed unaware that their products were inferior to the instruments made by Gabriel Daniel Fahrenheit two centuries before!

Using a clinical thermometer purchased at the drug store, a mother might find her child had an apparent temperature of 101 degrees, when, in fact, there was no fever. Or, far worse, the thermometer might indicate a light fever when the child was on the verge of delirium.

Lack of a national standard was one reason. While each manufacturer had, presumably, his own master instruments for control purposes, he could have them certified only by sending them to Europe. (Since clinical thermometers have a range short of the freezing and boiling points, they cannot be tested by direct use of these referents.) There were also cases of careless workmanship. But Bureau scientists quickly found an old reason for errors: the glass had not been annealed

in sealing the tubes. A thermometer might have given accurate readings at the factory, but err by a considerable margin some weeks later.

Some idea of the need for temperature standards in the United States is shown by the records of the Bureau's first year of work: 17,000 tests were completed—and 13,000 of them were tests of thermometers. The Bureau's first published circular announced its readiness to test thermometers for readings between 32 and 120 degrees Fahrenheit. Eighteen months later, still in temporary quarters, the Bureau was ready to extend this range: from −25 to 900 degrees. This was beyond the limits of mercury instruments; it included several other types coming into general use in science and industry.

Some were expansion thermometers using a gas, rather than mercury, as the medium. Gas thermometers were being used to measure temperatures up to 1,800 degrees Fahrenheit, but with dubious accuracy. Another temperature-measuring device had been used in a limited way since 1821: the thermocouple, an electrical device, measuring the voltage produced in a closed circuit of two different metals when their junctions are maintained at different temperatures. Still another relatively new electrical device was the electrical resistance thermometer, responding to temperature-caused variations in the resistance of a platinum wire.

A fifth type of instrument was just coming into use, the optical pyrometer, intended to measure extremely high temperatures in objects hot enough to emit visible light. The principle was comparison, to compare the intensity of the light from the heated object with the intensity of light from an object of known temperature. One method was to place the filament of an electric lamp between the observer and the heated object, using a color filter to limit the visible radiations from both to the same part of the color spectrum. By varying the current flowing through the filament, its temperature could be varied. When the intensity of light from the filament equalled that from the object, the filament became invisible against the background.

The principles of expansion, electrical, and optical thermometers had been known for some time. But it was a different matter to construct accurate instruments, and to have their accuracy certified. In the high and low ranges, who could say?

The first need, for science and industry, was that temperature-

measuring instruments, of whatever type, be consistent in their readings. Even if mercury thermometers could be standardized so that all gave the same results, their temperature readings would be dubious if gas thermometers gave different readings under the same conditions. Optical pyrometers were used in a temperature range inaccessible to mercury thermometers. How could they be standardized so that their readings were in appropriate relationship to those of mercury instruments?

To the individual who seldom encounters anything hotter than a kitchen oven, high temperatures and their measurement might seem, at first, to be mere laboratory concerns. But in fact, precise measurement and control of temperatures is a critical problem in numerous industries. In the early twentieth century, lack of reliable thermometers and pyrometers was a serious handicap to manufacturing.

The modern kitchen stove is porcelain enameled. After application of a ground coat to the panels, they are dipped or sprayed for the white coat, dried, then fired in a furnace. A typical firing schedule calls for the maintenance of a furnace temperature of 1,400 degrees Fahrenheit.

An endless-chain conveyor hauls panels through the furnace. They begin at room temperature, perhaps 70 degrees. In the furnace they are heated red-hot. When they are removed from the furnace, they carry with them a large quantity of heat. Unless this heat is replaced, furnace temperature drops sharply. Since the chain may carry a succession of different stove parts, some much heavier than others, the heat drain is not constant.

What happens if the furnace temperature is too high or too low? A small variation will cause "under-fired" or "over-fired" ware. There will be variations in the hardness and quality of the finish, and different degrees of whiteness. If a stove top and a side panel are fired at different temperatures, the difference in their colors will be apparent to a critical buyer. Since one spoiled part means a loss of five or ten dollars in labor and materials, precise temperature control is vital.

Many industries require such precise measurement and control of temperatures, often at even higher levels. Indeed, there are important

industrial processes which could not have been developed or put to use in the absence of precise standards and instruments.

At the lower end of the temperature scale, liquefied gases—hydrogen, nitrogen, oxygen, and helium—are finding increasing industrial and military uses. Nitrogen, to be liquefied at atmospheric pressure, must be cooled below −196 degrees Celsius. Hydrogen was once called a "permanent gas," since it was thought impossible to liquefy it. But it is being liquefied today in a National Bureau of Standards pilot plant operation, below −240 degrees Celsius.

This is little more than thirty degrees above absolute zero. But even lower temperatures are being attained and measured in the Bureau's low-temperature laboratory. Absolute zero is theoretically unattainable, but the Bureau can attain and measure points within a few *thousandths* of a degree of it.

Up the scale, the designer of a modern steam turbine deals with temperature around 650 degrees Celsius. A gas turbine designer works at still higher levels: 1,200 degrees. The modern metallurgist must know what happens to some of his materials in the neighborhood of 2,000 degrees. The rocket engineer must carry his data a full thousand degrees higher, to 3,000 degrees. The flame of an ordinary kitchen gas range, incidentally, may be as hot as 1,700 degrees Celsius.

Temperature measurement of a rather exact kind is needed by all these specialists. But even these temperatures are by no means the highest known, or the highest made by man. The inside of an atomic bomb fireball is hotter than one million degrees Celsius. At the instant of explosion, a hydrogen bomb hits about 100 million degrees. Some of the stars are much hotter!

Accurate thermometry could not have been developed without means for accurate measurement of length and mass. But it is equally true that accurate length and mass standards depend on accurate thermometry! Thus when the English scientists set up the conditions necessary to reconstruct the Imperial standards destroyed in the burning of Parliament, one requirement was a system of thermometry sensitive to changes of one hundredth of a degree.

With suitable instruments, other determinations can be made. Each substance has its individual capacity for heat, freezing point, melting

point. Substances differ in their electrical conductivity, and conductivity is affected by heat. Combustible mixtures have their ignition points.

These are among the *physical constants,* second only to standards of measurement as the fundamental data of research and all branches of engineering. From its initial work in the calibration and development of instruments, the National Bureau of Standards, of necessity, soon expanded its research to include accurate determination of a broadening range of these physical constants.

There is need for such constants, for example, in designing the simplest kind of household heating system, a furnace and radiators.

The furnace burns fuel: coal, oil, or gas. Each unit of fuel can provide a known quantity of heat. The heating potential of a ton of coal, for example, is given in British thermal units, Btu's. To deliver the maximum proportion of this heat, the conditions of combustion must be proper, including the supply of sufficient oxygen.

Three methods of heat transfer take place in the system. The inside shell of the boiler is heated largely by *radiation* from the fire. Heat passes by *conduction* through the boiler to the water inside. Heat is distributed through the water in part by radiation, in part by conduction, but primarily by *convection,* the warmed water expanding, becoming lighter, rising, being replaced by colder water.

Since water has a heat capacity 3,000 times that of an equal volume of air, it is an efficient medium to distribute heat through a building. In a hot-water system, convection moves the hot water up through the pipes. The cooler water, which has lost heat to the room radiators, descends through the return pipes, which feed into the lower portion of the boiler.

Steam radiators are smaller than hot-water radiators. One reason is that the rate of heat loss, the flow of heat from a hot substance to a cooler one, rises rapidly as the temperature difference between the two increases. A hot-water radiator may be 60 degrees hotter than room temperature; a steam radiator 150 degrees hotter. Though steam weighs less than water, volume for volume, it has an enormous supply of latent heat, which it loses in condensing, turning to water to drain back to the boiler.

As its name suggests, a radiator radiates some of the heat supplied

by the water or steam, which passes through the radiator shell by conduction. Heat is also distributed through the room by convection, warmed air near the radiator expanding and rising, to be replaced by cooler air. The "draught" of cool air you feel on your ankles may not be blowing under the front door. It is part of the convection pattern, usually blowing toward the radiator. Perhaps you have noticed a pronounced example of convection in the bathroom, if the shower is first turned on while the shower curtain is drawn. The hot water warms the surrounding air, which rises, and the cool air rushes in, blowing the lower part of the shower curtain inward and causing a breeze in the room.

Research at the National Bureau of Standards has contributed much to the design of even the simplest house-heating systems, as well as to the design of huge industrial furnaces. The engineer designing such a system needs accurate data on many points, such as how to distribute heat from the system where the heat is needed, and how to prevent the wasteful loss of heat where it isn't needed.

A radiator is a heat-loss device. If you were to surround the radiators and pipes of the system with insulating material, the furnace would use very little fuel, but it wouldn't heat the house.

Radiators are designed to lose heat as quickly as possible, by presenting a large exposed surface. But the house itself should be well insulated, so that it does not lose heat.

One continuous program at the Bureau is testing insulating materials, not to say which one is "best" but to provide precise data for engineering use.

Insulating materials are used to check all three kinds of heat loss.

Radiant energy, like light, can be reflected. Your house would be cooler on a bright summer day if the roof were covered with mirrors or polished metal, or glossy white paint. The efficiency of your heating system could be improved by lining all of your rooms with mirrors or polished metal, though such a decorating scheme might not be popular. Some insulating materials incorporate metal foil to reflect heat.

The materials of which your house is built—wood, brick, cement, plaster—are poor heat conductors, good insulators. But such large surfaces are involved that even a low rate of heat loss is significant. And,

though the rates are low, there are differences among these materials, and for materials of different thicknesses, which are enough to make a marked difference in your fuel bills.

Convection is a major cause of heat loss. Warm air escapes through cracks and crevices, often a surprising volume. But air is a poor heat conductor. Some of the best insulating materials are porous or cellular, entrapping air.

On the grounds of the Bureau is a small white bungalow, hidden inside a barn-like structure. Architects and engineers throughout the United States use information gained by experiments inside this full-scale testing device, where climate can be produced to order for the study of heating systems and building materials.

Here, then, is the complex of research in the science of heat and temperature and their applications in engineering: the discovery of physical laws, the establishment of standards of measurement, the determination of physical constants, the design and calibration of measuring instruments, and the study of the properties of materials and structures.

As research has pushed the frontiers of knowledge up and down the temperature scale, into regions of extreme heat and extreme cold, many strange problems have been encountered, with materials acting in odd ways, quite unlike their behavior in ordinary circumstances. At the temperature of liquid hydrogen, steel becomes brittle, a piece of rubber can easily be shattered into fragments, and plastics behave oddly. Near the region of absolute zero, metals become superconductors of electricity, losing all resistance. Low-temperature engineering has the task of finding materials which can safely be used in containers, pipes, valves, compressors, and other parts exposed to such chilliness.

The problems of high-temperature engineering are similar, to find materials which will stand up. Modern jet turbines make incredible demands on materials. The turbine may rotate at 15,000 revolutions per minute with some parts exposed to temperatures above 1,200 degrees Fahrenheit, while air at the intake sometimes is sub-zero.

Science and industry also need international temperature standards.

These have never been quite as difficult to achieve as standards of weight and measure, but some problems remain.

In 1948 the General Conference on Weights and Measures laid a foundation by recognizing the principle of the Kelvin absolute thermodynamic scale, which requires only one fixed fundamental point other than absolute zero. They chose the "triple point" of water. This is slightly different from the freezing point, used in the past. The triple point is the temperature at which ice, liquid water and water vapor exist together in equilibrium. Scientists say this point, only a hundredth of a degree above the ice point, can be determined more accurately. The 1954 Conference ratified this decision.

The absolute thermodynamic scale is used chiefly in the theoretical work. For everyday measurement, an International Temperature Scale was adopted, and temperature-measuring instruments are calibrated according to this scale. Like Fahrenheit's, it is based on fixed points. Essentially, it is the Celsius scale, with zero and 100 degrees as the ice and steam points.

But to extend the range of temperature measurement, new fixed points have been adopted: the boiling point of oxygen, −182.97, the boiling point of sulfur, 444.60, the melting point of silver, 960.5, and the melting point of gold, 1063 degrees.

Within the range of known temperatures, from absolute zero up to several million degrees, life as we know it can exist only within a tiny segment. Though men can live and work in temperatures below zero and above 100 degrees Fahrenheit, they do so at some risk of life and health, and only with the aid of special arrangements to conserve body heat or to permit the necessary evaporation of body liquids. Civilization, and life generally, depends upon plants and animals, most of which cannot withstand such "extremes." Indeed, it has been said that a sudden, permanent change in the world's climate of as little as twenty degrees, up or down, would, in a short time, bring our civilization to an end.

Able to survive in only a tiny band of temperatures, man, through his science, is attaining and using temperatures within a hair's breadth of the ultimate, colder than any cold this earth has ever known. At the same time he pushes against the upper limits, producing temperatures exceeded only by the sun and the stars.

8

THE SUN IS OBSOLETE

Since Joshua made the sun stand still, few men have been ingenious enough to tinker with time. In earlier centuries there were few temptations to do so, if only because the natural units of time were neither invented nor discovered by man. He lived by them, like other animals, before he walked on two legs. With the crowing cock, he rose at dawn. Like the small mammals, he feared night-prowling predators. As do the migrators and hibernators, he made provision for the months of snow and ice. The passage of the sun across the sky regulated his comings and goings. Until he invented numbers, he could not count the days between full moons, but he knew of the dangers and opportunities of this cycle.

When he became a farmer, he grew more sensitive to the passing of the seasons. Now he had a calendar of sorts: the first killing frost, the first snow, the freezing of the water hole, the deep cold, the thaw, the freshets, the spring leaves, the return of the birds, the days of heat, the days of fruit and harvest, and the turning of the leaves again.

Such outward events were unmistakable, but man had within his own body and mind a subtler sense of time. This, too, he shared with other animals. Bats sleep by day in the depths of caves, where no ray of sunlight penetrates; but each night they wake at dusk and spiral up and out for their daily food and drink.

Some men can set their private clocks, their time sense, for a certain hour, and wake at the moment they choose. Some can, at any

hour of the day or night, estimate the time shown by the public clock with good accuracy. Not everyone can do this. But everyone has a sense of time, and this private, subjective time is not necessarily the same as the time marked by the hands of the clock.

It is not surprising that man should have a time sense, for he exists in time, and his limited life span is a procession of events which take place within his body. His heart beats at a regulated pace. Nerve impulses reach his brain from his eyes and ears, traveling at a fairly constant rate. He breathes. He digests. His hair and fingernails grow; his eyelids blink; and in time his hair turns gray. His life is a series of chemical processes, taking place in time.

As every amateur photographer knows, time is a variable in chemical reactions, related inversely to temperature. If the developer is at 68 degrees Fahrenheit, the film is properly developed in 17 minutes. If the solution is warmer, the time must be reduced.

Many chemical reactions double or triple in speed if the temperature of the substance is increased by about 20 degrees Fahrenheit. And this suggests a fascinating question: Would man's time sense be changed by a change in his body temperature? Is his time sense a function of his body chemistry?

Everyone knows that time sense is affected by circumstances. When one is bored, or in pain, or in despair, time drags. Activity and pleasure make a day speed by. In moments of crisis, men are often able to integrate information and make decisions at speeds far beyond their normal capacities. Some drugs affect time sense, tampering with body chemistry. And there also seems to be a relativity of time, so a day seems longer to a child than to an adult. Perhaps this is because a year is half a lifetime to a two-year-old, but only a fiftieth of a lifetime to the man of fifty.

Persons with fevers caused by illness have been asked to estimate time. For them it seemed to drag. The experiments were repeated with healthy adults in whom fever was artificially induced; to them fifteen minutes by the clock seemed to be half an hour or more. Higher body temperature accelerated chemical processes, and their time perception was changed.

Man normally has a regulated body temperature, maintained within a degree or two of 98.6 degrees Fahrenheit. But there are animals

without such regulation, whose bodies become warmer by day, cooler by night, and cooler still in the winter months. Does this change their time sense? Laboratory experiments suggest that it does. In a room kept at constant temperature, ants and bees can be taught to come for food at a certain hour. If the room temperature is then increased, they come earlier! And one can learn to estimate the outdoor temperature with fair accuracy by counting the number of times a cricket chirps per minute.

Perhaps such animals have a time sense quite different from man's. To them a warm day may seem ten times as long as a cold night. And summer may seem ten times longer than winter!

What if man had a variable body temperature and perceived time as variable? With his senses telling him that a June day was many times longer than one in December, what evidence would persuade him to the contrary? The temperature change would affect all his senses, not merely his concept of time, among them his sensing of temperature! He would see no regularity in the motions of the heavenly bodies or the acceleration of gravity.

Fortunately, the mechanism that regulates body temperature permits adjustment to the regularities of nature, to the natural division of time into days and years. But what would time be if there were no such natural divisions? What would time be for a group of space travelers marooned on Venus, somehow able to sustain life but with no man-made timepieces and the sun perpetually hidden from view?

They would need some measure of time. Each man would have his own personal time sense, but the group would need a common standard to regulate group activities. Some arbitrary standard would be sought. They might set up a pendulum, or, more crudely, a water clock—a pierced bowl slowly sinking in a pan of liquid. They might use a candle of a certain thickness, marked in linear units. With parts to build a clock, they could devise a spring escapement, or they might arrange a motor-driven flywheel with a governor.

The solution might satisfy their needs, but it would not be a reliable standard. It would be subject to drift, variation, abuse, and loss. Unless they were able to find and use some natural standard, they could never be sure their clock was keeping time.

On earth man has natural standards: the solar day, the lunar

month, the year. Man observed his shadow growing longer and shorter in the course of the day. He fixed a stick in the ground and traced its shadow, the first sundial. To divide the day he marked the point where the shadow was shortest. He could then, if he wished, make further subdivisions by halving and quartering. But soon, early in history, he turned from his shadow to the stars and became an astronomer.

The priests of Babylon scanned the night sky from watchtowers, seeking to foretell the future by the advent of comets and eclipses. Carefully they marked the beginning of each lunar month. Here they found more of the ratios which plagued advocates of decimalization. There were twelve lunar months in the year. The Babylonian year was fixed at 360 days. They measured the time between the first appearance of the sun's disc on the horizon and its full disclosure, and found it to be 1/720th of a solar day. They divided the day into 12 periods, each double one of our hours.

The early astronomers were puzzled by some of their observations. They could observe that days were shorter in winter, and mark the path of the sun along the ecliptic, thus fixing the beginning of the year. But, thinking the earth was the center of the universe, they could not explain the apparent motions of the planets. The key to the explanation was at hand, though they did not use it. They noticed that the stars seem to move more rapidly than the sun, crossing the meridian about four minutes earlier each night.

But this is often puzzling to people who consider it for the first time, even though they know the sun is the center of the solar system, and that the earth both spins on its axis and revolves around the sun. Why is there precisely one more stellar day than solar day in the year?

It can be demonstrated with the help of a wastebasket. The wastebasket is the sun, and it is placed in the center of the floor. The walls of the room are the sky, each object on the walls a star.

You are the earth. Choose a "star" as your reference point, and stand so that you face neither the star nor the sun.

Now you must walk in a circle, an orbit, around the sun, counterclockwise. At the same time, spin on your vertical axis, also counterclockwise. To simulate the earth, you should spin 365 times in making a single revolution around the sun, but you might soon be too dizzy

to count. Two or three spins will be enough. Each time the star or sun crosses your meridian, the point in front of your nose, count it. When you return to your starting point, facing the original spot, you will have counted the star once more than you counted the sun. It will have crossed your meridian one more time.

The early astronomers concocted elaborate theories, but they missed the right one. Indeed, Pythagoras, in the 6th century B.C. was the first man to teach that the earth is a sphere floating in space, an opinion far from universally held two thousand years later. Even fewer people were impressed in the 3rd century B.C. when a compatriot of Pythagoras, Aristarchus, declared that the puzzling motions could be explained by the theory that the sun, not the earth, was the center of all things. Some 1800 years later, Copernicus somewhat hesitantly revived this ancient theory and laid the foundation for our present understanding of the solar system.

Of course it was not convenient to consult an astronomer whenever one wanted the time of day, and they kept odd hours, anyway. Men who had numerous servants used water clocks or hourglasses. But these had their faults, and marked candles sometimes blew out. The sun was more reliable, although it changed from season to season.

The first crude mechanical clocks were made about a thousand years ago. In 1288 the first clock was placed in the Westminster clock tower, and a few years later another was installed at Canterbury. The two seldom agreed. Apart from their mechanical limitations, it was impossible for them to be "right," for how could they be set? One could not fix the time in an observatory and carry it to Westminster by hand, like a pound weight. Yet they were seldom very far wrong, for they could be adjusted each day by means of sundials.

That was good enough. There were no trains to catch.

But there was a little annual discrepancy of thirty minutes or so. Everyone knew the sun rose later and set earlier in winter, but it was assumed that noon, the time when the sun crossed the meridian, was unvarying. But as the clockmakers gained confidence in their skill, they began to have some doubts about celestial mechanics.

Once the Copernican theory gained credence, it was possible to do something about that 30 minutes. Knowing the earth revolves and rotates, one more fact is needed: that it is tilted on its axis. Thus the

solar day lags behind, then catches up, with a maximum variation of about 30 minutes each year. Once this was understood, sundials could be improved by setting their index bars aslant, like the earth's axis.

In 1675 the Royal Observatory at Greenwich was built, the home of modern timekeeping. There was a new definition of the day, the one we now use, the mean solar day, based on an imaginary sun moving at a uniform speed along the equator. Mean noon is when this imaginary sun crosses the meridian. The Royal Observatory, like the United States Naval Observatory, established in 1842, was primarily an aid to navigators, who depended on chronometers in fixing their positions by sextant. In the United States, "Navy time" is still the standard for the length of the day.

Though our day is the mean solar day, it is determined by observation of the stars. At the Observatory in Washington—when weather permits—stars are photographed through a zenith tube, so called because it is permanently mounted in a vertical position. More than one star is photographed, but only those which cross the meridian near the zenith. Each star is photographed twice, just before and just after crossing, and its instant of transit is computed from the two observations.

These nightly observations are used to correct a number of pendulum and quartz crystal clocks, the corrections amounting to a few thousandths of a second. The average of these clocks becomes the official standard, the setting of the master clock.

Our day is the Navy day. But subdivision of the day into minutes, seconds, and smaller units, is the business of the National Bureau of Standards, which maintains the national standards of frequency.

The original problem was an old one: accurate subdivision of an accepted unit. For nine centuries the best solution was mechanical, a clock. When Galileo observed the regularity of pendulum oscillations, clock-making took a long step forward, and by the twentieth century pendulum clocks could be built which erred by less than one hundredth of a second per day.

In the early part of the twentieth century, another natural standard was found, a frequency standard more precise than the pendulum and not dependent on the pendulum's mechanical properties. Walter Guy-

don Cady, professor of physics at Wesleyan, was the leader in experiments with piezoelectricity ("pie-ease-oh"), literally, "pressure electricity," electricity or electric polarity caused by pressure, especially in crystallized substances, such as quartz. Pierre and Jacques Curie had discovered, about 1880, that some crystals, when compressed in particular directions, show positive and negative charges on certain portions of their surfaces. The polarization is produced by mechanical strain in the crystals. Conversely, a crystal becomes strained when electrically polarized.

Some years later a French scientist, Paul Langevin, conceived the idea of exciting quartz plates electrically to produce sound waves of high frequency, and to use them as receivers which would pick up high-frequency sound waves and reconvert them to electrical charges. Here was the beginning of ultrasonics, the use of high-frequency acoustic waves. One early application was in the echo method of plotting the profile of the ocean bottom.

Cady's work led to the development of the piezoelectric resonator, used as a stabilizer, oscillator, and filter. Resonating crystals are used in radio broadcasting stations to control and monitor signal frequencies; they are also used to build quartz-crystal clocks, vibrating quartz plates taking the place of pendulums. Resonators have been constructed which respond to frequencies ranging from those of audible sound to more than a hundred million cycles per second.

Our national standard of frequency is a set of ten quartz crystals, carefully prepared, checked against astronomical data, and kept in the custody of the National Bureau of Standards. They provide time intervals accurate to about one part in 100 million.

But of course one cannot ask an astronomer or a physicist for the right time whenever it's needed. Astronomers had been making quite accurate time observations for a couple of centuries and more, and the pendulum clocks kept in observatories were likely to be very accurate. Indeed, clockwork mechanisms were built to drive their telescopes, so that an instrument pointed at a chosen star would follow it across the night sky.

Clocks and chronometers could be sent to observatories for setting and regulation. Not pendulum clocks, of course; bouncing about in a wagon would defeat the purpose of the journey. But if several good

spring-driven clocks were carefully padded, their average reading after the trip would be quite reliable.

But this was too inconvenient to do often, and few people had enough interest in accuracy to take the trouble. In most communities the town clock was a good enough "standard" for all—no matter what it read; it was adjusted occasionally by the sun, sometimes with instruments, often by guess.

The railroads needed something better, when they began to link towns and cities. They needed something different, too, from the custom of calling it "noon" when the sun was nearest the zenith. In any one community, this was appropriate, for the day was thus divided into equal parts. But this made noon in Boston 11:56 in Worcester. Noon in Chicago was 12:06 in Indianapolis. It was 11:36 in Pittsburg when the noon hour struck in New York City.

Now, with trains traveling westward, what time could trainmen adopt? They could not conveniently correct their watches by four minutes for each degree of longitude. Nor they could adopt, briefly, the time of each community through which they passed.

At first each railroad did what each community had done: adopted its own arbitrary noon. Usually railroad time was the time of the community where the road had its main terminal. Before long, there were almost as many "standard" times as there were railroads. A traveler who planned to transfer from one road to another had to cope with three city times and two railroad times, and he was lucky to make his connection.

The coming of the telegraph promoted standardization; in 1865 the telegrapher-station agent became an official timekeeper. In due course the railroads got together and agreed on a plan. Their lines would be marked off in time zones, with one hour changes at each boundary-line, and no changes of less than an hour. Important junctions, terminals or division points were chosen as the places where the one-hour changes would be made.

Cities and towns along the rights of way soon adopted the railroads' time standards, and town clocks were regulated by station clocks. It was still a matter of local option. A town not on the railroad might keep its local time. Some towns lay between marketing centers in two

different time zones, and there were arguments in town meetings over the choice of zones, deciding with which center to "affiliate."

Since the earth had been divided into 360 degrees of longitude and the day into 24 hours, it was reasonable to divide the earth into 24 time zones, each an hour apart, each spanning 15 degrees. In 1884, twenty years after the first time signals were sent by telegraph, an international congress recommended this plan, specifying that the zero meridian be the one passing through the Royal Observatory at Greenwich.

A few reformers wanted to go further, and they urged the congress to adopt "world time" or "universal time" with a 24-hour clock, all of the world's clocks to be set by the meridian clock at Greenwich. Thus Londoners would breakfast at 8, New Yorkers at 13, and San Franciscans at 16. The official day would begin at local midnight in London—but at local midday in New Zealand. Most delegates to the congress were unsympathetic.

The United States accepted the plan in part, agreeing that Greenwich Time should be the base, and that standard times in this country should be 5, 6, 7 or 8 hours behind Greenwich. But it was 1918 before time zone boundaries were drawn and officially adopted.

Congress had finally decided that the country needed official zones, and the Interstate Commerce Commission was directed to draw the boundaries. The 15 degree meridians were used only as a rough guide. In effect, the new boundaries were simply lines drawn to connect the zone divisions on which the railroads had agreed. Maine's eastern boundary with Canada divided Eastern Standard and Atlantic Standard time. Texas refused to be divided by a time zone, so the Central Time zone was pushed far to the west. Even time zones are bigger in Texas, 25 degrees wide instead of the normal 15!

Nowadays, when some states and counties prepare to make their annual decision on the change to Daylight Saving time, local newspaper editors usually receive a few letters of protest. Someone always declares that Daylight Saving time is irreligious, that man should not thus tamper with what the writer calls "God's time." Strange, indeed, that "God's time" should be a rather recent invention of the railroads, and be administered by the Interstate Commerce Commission!

With time divisions thus happily arranged, timekeeping might seem

to be a matter of mere mechanics. Soon the telegraph companies found that they could sell time. The Naval Observatory makes its signals available to anyone who provides the necessary lines to its transmitting room. There are several services available today: "noon beats," a three-minute transmission ending at noon, which railroads and airlines use to correct their timepieces; "jeweler's beat," a day-long transmission of coded impulses, by which jewelers and watchmakers regulate their instruments; and an automatic service which regulates clocks leased by telegraph companies to their subscribers.

The National Bureau of Standards makes frequency signals available by means of its broadcasting stations: WWV in Maryland and WWVH in Hawaii. For technical reasons, these frequency signals are somewhat more precise than time signals transmitted by telegraph. They are uniform within 0.001 second per day. Orchestras and musical instrument manufacturers are among the regular users of these broadcasts, for one of the signals transmitted is a pure tone, A above middle C.

Little more than a generation ago, most people still set their clocks and watches by the town bell, the fire siren, or the whistle on the factory roof. Now a $3 electric clock reports the time more accurately than the best of the old grandfather clocks. One might argue that it isn't really a clock, at least not a time-keeping instrument, but rather a time-reporting device. Almost all electric power companies have adopted the practice of operating in synchronization, generating alternating current at a standard 60 cycles per second. An ordinary electric clock is driven by a synchronous motor which responds to this 60-cycle current. If such a clock were plugged into a system supplied by a 50-cycle generator, it would lose 10 minutes per hour.

There are minor variations in this frequency, but they are corrected, so that an electric clock neither gains nor loses time and may never need resetting—unless something goes wrong. A power failure or a blown fuse stops the clock, of course. Once a New England power plant operator failed to read an announcement that WWV was making a change in its signalling code on a certain night; the following morning a large section of New England had slipped several minutes behind the rest of the world.

All this timekeeping machinery has been based upon the natural standard, the earth's rotation. Until quite recently it was thought that this rotation is constant. Then astronomers gathered evidence that the earth's spin is, in fact, irregular. It is slowing down, losing about one second in 6,000 years. What is worse, its rate of spin varies a little, a variation of about one part in 25 million, for reasons not yet fully understood.

One part in 25 million isn't much, about 0.003 second per day, but it is more than enough to make scientists unhappy. Their present methods and instruments are capable of substantially greater precision, but only if they can be related to an even more precise standard. Had we reached the upper limits of accuracy in timekeeping? Greater accuracy is needed in some fields, such as radar. Many measurements—the acceleration of gravity, the speed of a projectile, and radio frequencies—are dependent on a time standard, and the accuracy of the standard limits the accuracy of measurement.

To meet the need, scientists at the National Bureau of Standards set out to find a new standard of time. They found it first in the heart of a molecule of ammonia. This molecule has the shape of a pyramid. Three atoms of hydrogen form the base. The apex is an atom of nitrogen. This nitrogen atom vibrates up and down, back and forth through the base. It vibrates at a fixed frequency: 23,870,100,000 cycles per second, or 2,062,376,640,000,000 times while the earth spins once on its axis.

Dr. Harold Lyons, Bureau scientist, explains: "Although high, the vibration rate or frequency was still low enough to enable the counting of the oscillations, yet was high enough to achieve good accuracy."

The Bureau's first atomic clock made use of a tube filled with ammonia gas. Oscillations of a quartz crystal, multiplied, are used to generate a radio wave with substantially the same frequency as the frequency of the ammonia molecule's oscillations. By electronic means, the two are constantly compared. If the signal controlled by the quartz crystal does not match exactly, control circuits automatically detect the variation and correct it. The first model of the clock proved accurate to one part in 20 million, not quite as good as the earth. Later models have surpassed this, and experiments with a cesium beam indicate that an accuracy of one part in 10 billion may be attained.

Scientists are slow to discard an old standard and adopt a new. Until there is more experience with atomic frequencies, the ten quartz crystals will continue to be the official national standards of frequency. It will be longer before a frequency standard takes the place of Navy time, the earth's rotation, as the measure of the day.

If men some day travel into space, they will need and have a newer time standard. Leaving the spinning earth, they will no longer see time in the sky. But a more precise natural standard, the atom, will be with them wherever they go.

9

THE MEANING OF STANDARDS

His metric legislation failed, but Congressman Southard had better luck with another bill he sponsored in 1901, creating a new federal agency, a National Bureau of Standards.

One Member asked suspiciously whether this wasn't a back-door approach to the metric system, noting that the same people were supporting it. Southard reassured him, but it was true that both bills arose from the same circumstances: the rapid expansion of industry in America. If that trend were to continue, better standards were needed, whether metric or English.

Hassler's standards were still in use, but the old Office of Weights and Measures in the Treasury Department wasn't equal to the new demands. Its annual budget was less than $10,000. State services were in even worse shape, and few were doing much to promote standardization. State laws were antiquated, some virtually unchanged from colonial times.

In any case, standards of length, weight, and volume were only a part of the problem. Other standards, such as a standard of temperature, were badly needed. Mere custody of physical objects no longer sufficed. England, France, Germany and Russia were advancing in the physical sciences, and all four had fine national physical laboratories. American science was lagging behind.

Not custodial service but a broad program of physical research was what the nation needed. Not simple measurement, but precise deter-

mination of physical constants: values, fixed authoritatively, for the freezing, melting, and boiling points of many substances; specific gravities; coefficients of expansion.

The need was broader still, though it did not come out in the debate, and few Congressmen could have realized the significance of the new name, National Bureau of *Standards*. The United States, in 1902, was on the threshold of a new age, the age of standardization.

Standardization, in this broader sense, is not an invention of man. Natural selection is a process of standardization. Living organisms do not form a continuum, an imperceptible merging of species into species. The Maryland yellowthroat is unique among birds, the porpoise among mammals, the coral snake among reptiles. Each has distinctive characteristics, standard characteristics, passed on from generation to generation. The atoms of each element are like each other, different from other atoms.

"Standards" also means agreements or practices. Bees build honeycombs to a precise standard. The oriole's nest is distinctive. Many living things have mating rituals, warning cries, recognition signs and hunting tactics.

One of man's unique characteristics is his ability to invent and accept new standards, such as in dress, social conventions, laws, and diet. While all species transmit characteristics from one generation to the next, man alone expands his heritage. One of his means is language, the standardization of grunts and squeals, each assigned a specific meaning. Man is also unique as an innovator, seeking the new, repudiating or even destroying old standards. Words like "unique," "invent," "progress," "change," "discover," "new," and "unprecedented" have a good sound, suggesting admirable things. We admire inventors and discoverers.

To progress, to change, is to depart from an old standard, and there is a conflict between innovation and standardization. The conservative clings to an established standard that has stood the test of time, the customary way, the traditional. The innovator is thought of as a radical, an enemy of standardization.

The conflict between old and new, the standard and the innovation, is real but far more complex than such easy generalizations describe. Man is by nature an innovator, but he is also a standardizer, and if he

were not he could not long survive. An innovation is successful only when it has become a new standard.

The ability to innovate might save a man's life if, like Robinson Crusoe, he were marooned for years on a lonely island. The habits and customs of his former life would not save him. He would face new problems, which he would have to solve in new ways. He might, for example, experiment with various means of catching fish. If he found one that worked well, would he discard it and continue innovating? No, his solution would become a standard method, to be followed until it failed him. He might make further experiments, but not to the exclusion of his proven technique.

Society places limits on innovation, for the excellence of individual solutions is secondary to their practice by the group. Each member of a tribal community could, if he chose, build a different kind of hut, one of clay, another of grass, another of wood. But if such individuality were characteristic, there would be no tribe, no community ties, no benefit from association.

Throughout history inventors have been dismayed to discover that it is not enough to invent something new or better. The conservative attitude—Adams called it "the stubborn tide of prejudice and the headlong current of inveterate usage"—is strong because it is so much a part of survival.

Progress occurs. In manufacturing, it was made more easily in the past, when life was simpler and social groups smaller. If a man made an improved weapon he could try it; if his fellows admired it they could copy it; its popularity in one village might spread to the next.

Often a new idea and an old standard collide. Or two standards, each with some adherents, come into conflict, one threatening to drive out the other. What happens depends, in part, on the attitudes of people.

It is difficult to say just how people do feel about standards. A woman will not be seen in a dress that is out of fashion; she will not be so different from other women. Yet she will be upset if she sees another woman wearing an identical dress. Prefabricated houses were once called impractical because home buyers insisted upon individuality; yet today people flock to suburban developments where homes are as alike as grass huts in a tribal village. A man needs some in-

dividuality to attract favorable attention, but a shade more of difference makes him a social outcast.

Fashion and prejudice have a strong influence, but in manufacturing there are also controlling factors of mechanics and economics. Eli Whitney is often called the father of mass production, the system of interchangeable parts, but both titles are too sweeping. The arrows and bowstrings of ancient peoples were interchangeable. Indeed, ancient standards of design and production were so distinctive that an archeologist can examine a shard of pottery and identify its place and time of origin.

Whitney did not invent a gun, nor were his guns the best made. Nor, in the real sense of the term, did he invent mass production. What he did was standardize production operations and narrow tolerances for the dimensions of parts. In Whitney's plant, an individual worker did not make a gun; he made a part of a gun, not knowing which of the parts he made would be fitted to which of the parts made at the next bench. The test came at assembly. If each part were standardized, a gun could be built up by joining parts with no hand fitting.

But genuine mass production cannot occur within the limits of a single plant. It requires standardization to an extent never imagined in guild days, an industrial complex, each plant integrated with others.

The mass-producer of a kitchen stove, for example, does not make an entire stove. He buys sheet metal, and his costly press dies are designed to shape steel of a certain gage, a standard dimension. He buys many finished parts—thermostats, screws, bolts, clocks, washers, pipe, electric wire, springs. If there were no standards for these items, each step in the assembly of each stove would be a unique problem. As it is, he can buy from a number of supplying companies, according to accepted standards, sure they will meet his specifications.

On the assembly line a worker dips into one bin for a bolt, into another for a nut. The two may have been made by different suppliers, but their threads mate. If they did not, no assembly line could function. A complex device such as an automobile or airplane has thousands of threaded parts. They must fit without selection, machining, or hand fitting. A time study may allow five seconds to fasten two

parts together. If the two were not produced to the same standard, the operation would be brought to a halt.

We take it for granted that any light bulb we buy will screw into any household socket, but there was no such standardization when the electric industry was young, as those who have seen Edison's early lamps know. Manufacturers offered 175 different lamp bases, and that was only the beginning of the diversity.

There were only a few companies making generators, which somewhat limited the variety of voltages and cycles. But one circumstance introduced variation, at the cost of considerable inconvenience later. The early light bulbs had carbon filaments. No manufacturer could standardize these filaments so all would perform satisfactorily at a standard voltage. Rather than scrap bulbs requiring a higher or lower voltage—which would have been expensive—bulb manufacturers created markets for them. They approached communities installing their first generating plants and persuaded them to adopt voltages suitable for their off-standard bulbs.

Within a few years, tungsten replaced carbon filaments. The trouble began when electrical appliances were marketed, for small voltage differences are enough to cause improper operation of motors and heating elements.

The United States electrical industry soon agreed on standards. There are only a few standards for lamp bases, for example: the common household type, the jumbo, the smaller varieties used for Christmas tree lights, special types for automobile headlights and flashlights. Wattages are standard; you cannot purchase a 43-watt or a 90-watt light bulb. European industry was less successful. A European lamp maker once complained that he had to supply 8,000 types to meet his customers' demands.

There are many familiar examples of standardization: railroad track gage, bottle caps, shoe sizes, paper sizes, automobile tire sizes, the length of shoelaces, and so on. These are standardizations of end products to facilitate customer use, making them compatible with other products.

Much more significant in the development of industry was standardization of production materials and parts, tools, instruments, and other elements. Such standardization was gaining momentum at the

turn of the century. Manufacturers were working out industry-wide agreements, and inter-industry agreements. But the foundations on which they sought to build were uncertain. The first requirement was a common language of measurement. The second was equipment, measuring instruments conforming accurately to the standards. Neither was available in the United States.

The National Academy of Sciences had called attention to the need at its annual meeting in 1900: "The facilities at the disposal of the Government and of the scientific men of the country for the standardization of apparatus used in scientific research and in the arts are now either absent or entirely inadequate, so that it becomes necessary in most instances to send such apparatus abroad for comparison."

The Navy had to send navigating instruments to Germany for calibration. Industrial thermometers and industrial measuring instruments were of unknown reliability unless they bore the seal of a European testing institution. The young electrical industry was hampered by the lack of standards and instruments. Chemists and pharmacists could buy some laboratory glassware in the United States, but none certified in this country for accuracy.

So the old Office of Weights and Measures was hopelessly inadequate. Though it had had custody of the official standard of length, the meter bar, for ten years, it had never had the resources to subdivide it! Thus the most elementary measuring devices, those used to measure length, could not be calibrated by the only official source in the United States.

Manufacturers might agree on specifications, but they had no certain meaning. There were needs for instruments, but no instrument industry could be developed here in the absence of standards. Thousands of gas meters were in use, and some cities had appointed men to inspect them. But how?

So, when Secretary of the Treasury Lyman J. Gage asked Southard's committee to abolish the Office of Weights and Measures, in his own department, and set up a new Bureau, there was little opposition. "No more essential aid could be given to manufacturing, commerce, and the makers of scientific apparatus, the scientific work of the government, of schools, colleges, and universities," the committee reported.

No witness appeared in opposition, and the bill was carried in both houses by voice vote.

The charter given to the new Bureau reflected the changes taking place in science and industry. Of course the Bureau would have custody of the basic standards, and it was directed to provide service, verifying instruments submitted to it, for a fee. It was directed to construct new standards when necessary. There was a further point: the Bureau was authorized to enter into a new kind of research, to determine physical constants and the properties of materials.

The Congressmen appropriated less than $40,000 for the Bureau's first budget, and several wondered, for the record, if that were not too much. But this was the beginning, a decision that the Government of the United States would, from then on, participate in fundamental scientific research.

The new Bureau took over custody of the meter bar and kilogram and began work on equipment to provide service to those who wanted measuring instruments verified. Even this called for research. Until the Bureau had determined certain physical constants, such as coefficients of expansion of metals, the fundamental standards could not be well used.

Other needs were also urgent. To test electric lamps, a standard of brightness was required. Once the standard was defined, accurate instruments were required to use it. And at this point, early in its history, the Bureau took a step beyond standardization:

Industry needed a rapid commercial photometer to test electric lamps, and no such apparatus was being manufactured. The Bureau's electrical laboratory developed one. Other instruments were developed to measure electrical current, electromotive force and power, and other properties of electricity. These instruments became standard measuring devices, produced by private manufacturers, calibrated against the Bureau's standards.

The next step was almost imperceptible, yet it meant a further extension of the Bureau's work. Measuring instruments were being tested; the government had no other testing laboratory so well equipped; why should not the Bureau test materials, too?

Having developed a photometer, the Bureau was called upon to

test electric lamps purchased by Federal agencies. Other requests soon came, to test iron, steel, brick, stone, cement. Director Samuel W. Stratton reported to Congress: "There are in this country no uniform methods or apparatus for the testing of wood, paper, textile fabrics, inks, mucilage, etc. The development of standard methods and apparatus for this purpose, and the careful calibration of such apparatus for the Government Departments, large consumers, and manufacturers is an important work the Bureau ought to do."

Though intimately related, measurement and testing are by no means the same thing. The number of different units of measurement —the inch, pound, volt, etc.—is limited. Physical objects can be measured and their properties such as density and conductivity determined.

Testing, however, is usually an attempt to determine how a material or device will perform. Some tests are quite direct; a voltmeter can be tested by using known voltages. Other tests are indirect, because of the complex properties which may contribute to performance.

For example, a manufacturer or, perhaps a purchasing agency, may wish to know how well a certain type of corrugated fiber carton will withstand conditions of use. These conditions are highly variable; indeed, no two cartons will encounter precisely the same conditions. A carton in transit will have others stacked upon it; it will be shaken, vibrated, dropped; it may be struck by pointed or blunt objects; it may be exposed to heat, cold, dampness, moisture. No single measurement or test can determine, in advance, how such a container will react to hard treatment. Yet it is known that there *are* differences among containers; some perform better than others. So—how can they be tested?

This kind of testing cannot be as precise as measurement. No combination of tests will predict exactly how an individual carton will perform, because of the uncertainty and variety of the conditions to which it may be exposed. But testing may make it possible to compare the merits of materials and construction details, so that one can predict that one type of container will perform, on the average, better than another type.

Some tests simulate conditions of use. A carton may be subjected to compression, vibration, dampness. It may be tumbled in a revolving drum, dropped on a platform in various positions, or placed on a roll-

ing cart which strikes an obstacle to simulate the impact of freight cars. Components of the carton may be tested in a variety of ways. Paper may be tested for bursting strength, flexure, resistance to tearing, tensile strength, puncture resistance, wet strength.

A mass of data can be obtained from such tests, but what does it all mean? Tests are not equally significant. One could devise a test which, although it determined a property of the material, told nothing relevant to product performance.

The central problem in testing is not devising or making tests. Rather, it is to discover what kinds of tests are significant and how their findings can be integrated. The goal, and it may take years of research to attain it, is a standard testing method.

The new National Bureau of Standards was soon busy with test development. It was only a short step to the *standard specification,* a standard of quality, a standard of performance, or both. As standard testing methods were developed, government agencies began buying products by specification; they called on the Bureau to assist in writing standard specifications.

In its first decade, the Bureau was caught up in the almost explosive expansion of industry and technology. Director Stratton had this to say in 1912:

> "Standardization of industrial processes and products and the application of precise methods in science and technology have made it imperative that the Bureau keep in close touch with the advancing needs for such work, and, as far as practicable, be prepared to meet such demands. The quality of materials depends upon their physical and chemical properties, each of which may be measured and standardized exactly as their dimensions are standardized. While this fact is already becoming a most fruitful factor in industry, its full application must quicken industrial progress to an extent which can hardly be overestimated. . . ."

There was soon greater need for haste and a demand for greater standardization. The United States went to war.

The War Industries Board appointed by President Wilson to manage war production seized upon standardization as a basic strategy, to

conserve materials and production capacity. Manufacturers were ordered to cut down on the varieties of civilian goods. Board orders eliminated 5,500 styles of rubber footwear. There were 446 models of washing machines on the market; the Board eliminated all but 18. Farm implement manufacturers were told to drop 550 types of harrows, leaving only 38 designs in production. Conservation orders went out to almost three hundred industry groups.

These were emergency measures, but they had unexpectedly lasting consequences. Wholesalers and retailers learned, for the first time, what it meant to have manageable inventories; and when the war was over their demands for variety were much subdued.

Herbert Hoover was impressed by the effect of conservation orders, product standardization; he saw the production of needless varieties of goods as a great waste. When business declined in 1921, Hoover was president of the Federated American Engineering Societies. Under his leadership committees were appointed to see how much more waste could be eliminated. The committees' report stimulated another wave of standardization, this time voluntary, organized by industry groups. Many present-day trade associations had their beginnings in this movement; they were organized initially to draw up codes of standards.

The makers of paving brick met in Washington, and Hoover was the principal speaker. Those assembled, pooling their information, found that together they produced 66 varieties and 9 sizes of brick. In less than 6 hours they agreed to eliminate 55 varieties.

There were many such meetings in many industries, some formal in their procedures and conclusions, others so informal that only the results were evident. The central idea, limiting varieties, was necessary to mass production, but it violated a favorite precept of salesmen and merchandisers. For years they had preached to dealers that it took a "full line" to attract customers; the greater the variety offered, the greater the likelihood of pleasing everyone. Dropping an unprofitable model was good sense, but it was shocking to think of wiping out lines that had paid their way.

It could not have been done except by industry agreements. Any manufacturer would have hesitated to cut his line of fifty styles to a dozen or so, if his competitors were not going to do the same. But if all did it, no company would lose and all might gain. In the end, there

was one decisive argument. Fewer models meant lower tooling costs, fewer change-overs, lower parts inventories—lower costs all along the line. When customers saw the lower prices, they would modify their desire for variety.

At first, the National Bureau of Standards was not directly involved in this kind of standardization, for it is a matter of trade rather than scientific, policy. But when Hoover became Secretary of Commerce a few years later, he directed the Bureau to set up new divisions to promote the adoption of commercial standards and simplified practices. Director Stratton objected that this was not the kind of thing the Bureau ought to do, but Hoover overruled him.

Stratton had good reason to object, for commercial standardization is anything but a research problem; it was loaded with controversies, long-range implications, and hazards. As a scientific agency, the Bureau might not be immune to political attack, but a scientist can stand his ground when he has the facts on his side. But commercial standardization opens up economic and social questions to which there can be no iron-clad answers.

To be sure, some measure of product standardization is essential to mass production. But how much? Where does it make sense to draw the line? Standardization has obvious virtues, it also has drawbacks, and there are serious potential dangers.

Some thoughtful men foresaw a threat to human individuality. Individual examples of standardization might seem trivial: slicing all bread to the same thickness and limiting the number of can sizes. But when thousands of such limitations were added together, where would it end? If five hundred varieties could be reduced to twenty-five, why not to one? Were we on the verge of building a machine-like society in which everyone dressed alike, ate alike, and—ultimately—thought alike? (The rebuttal to one prophecy of doom chided the prophet for having written a *syndicated* news article.)

Some manufacturers bucked the trend, and within limits many still do. They limit the variety of their offerings, but they are unwilling to make parts of their products interchangeable with the parts of competing products. Sometimes they protect their standards by patents,

thus, for a time, enjoying a monopoly in the supply of replacement parts.

But this is only a side issue, overshadowed by the wave of standardization that swept America after World War I. In the upsurge of mass-production industries, few could foresee that standardization might become, some day, a serious impediment to progress.

In a less industrialized society, it is not difficult for a new standard to replace an old one. The musket replaced the crossbow gradually, and in turn was replaced by the rifle. The automobile upset the horse-and-buggy industry, so that carriage-makers and blacksmiths had to seek other occupations, but for two decades horses and horseless carriages shared the highways. In our complex industrial society, however, there has been built up an almost infinite series of interrelated and interdependent standards. A standard which becomes universal may also become impregnable, so well entrenched that the cost and complexity of replacing it, even with a superior standard, is prohibitive.

An example is our system of weights and measures. In 1779 we could have adopted the metric system more easily than we adopted the horseless carriage a century later. By 1902 the difficulties had mounted. Today almost no one believes there is a serious possibility of making the change. English measure has probably become a permanent, irreplaceable standard, despite its inferiority.

The standard household electric voltage is 120 volts. Some foreign countries have standardized at higher voltages, such as 220. This higher voltage has advantages, and some household appliances require it. Fortunately it is available, though owners of older houses often find that installation of such an appliance often costs more than the appliance itself.

But it seems most unlikely that this country could change from one standard to another now, making obsolete the enormous investment people have made in 120-volt lamps, irons, clocks, and other devices.

Standards must be fixed before any new industry can begin mass production. Before there could be commercial television broadcasting, several standards were needed, so that receiving sets and broadcasting stations would fit together. Space had to be set aside on the frequency

spectrum, for example, and the number of scanning lines in the picture fixed.

Engineers debated how to fix the scanning pattern. The one that would work best at the time offered immediate advantages. But what if, within a few years, they discovered new principles, or ways to design superior equipment which would require a different pattern?

Once made, the choice was likely to be difficult or impossible to change later. Yet it had to be made, and made within the limits of what was then attainable, if commercial television broadcasting was to begin. If it did not begin, how would further research and development be supported?

The inertia of a standard is seldom absolute. Now we are to have color television, for example, with color telecasts which can be received by black-and-white receivers, and color receivers which can also receive black-and-white. A new frequency band is open, and converters can be attached to existing sets.

At times two or more standards can coexist, a new one winning acceptance, yet not driving out the old. Two attempts were made to displace the 78 r.p.m. phonograph. Both attempts succeeded and failed, so record players now operate at three speeds.

The new standards were superior to the old. But consumers were unwilling to scrap their 78 r.p.m. record collections; and so long as there are people who want to play 78 r.p.m. records, manufacturers will make turntables for their use. Further, so long as people own 78 r.p.m. turntables, record companies will probably produce new records to be played on them!

So this battle was fought to no decision, as others have been. Electricity displaced the gas light but not the gas stove. Television did not destroy radio, nor radio the phonograph.

Even total displacement is not necessarily difficult. Ferries disappear when bridges are built. Whole cities have converted from manufactured to natural gas, even though this required adjustment of every gas-burning device in every home and business. Railroads have converted from narrow to standard gage with only brief traffic delays.

But standards may have inertia, an inertia which increases to the point where it seems absolute. A standard may represent not merely a way of doing something but a vast and growing capital investment,

a critical part of the nation's economy, and be so integrated with many other standards that change could not be made without a tremendous upheaval.

Surface transportation is the most conspicuous case. Buses have been displacing trolleys. Automobiles, trucks, and buses have forced abandonment of considerable rail trackage, and railroads are seeking to abandon service on additional lines. The road vehicle has come to fill a more and more important place.

Imagine that a group of engineers and inventors were given this statement of a problem: "Here are the requirements our society has for surface transportation. Make a fresh start. Applying all that science and engineering know today, design the best possible solution."

If they could, somehow, erase from their minds all thought of present modes of surface transportation, yet retain all they knew about motive power, traffic requirements, and basic resources, what would they design?

Their solution would probably present new forms, none resembling the automobile. For while the automobile is a wonderful machine, in less than half a century it has become technically obsolete—not in itself but as a desirable standard. Capable of high speeds, automobiles crawl at less than walking pace on the streets of major cities. Highways are choked with traffic, and even a vast highway construction program will lag behind the increase in the number of vehicles.

How wasteful it is! A man weighing less than 200 pounds uses nearly two tons of machinery to carry him to work. In transit his machine occupies over a hundred square feet of road space, but it demands free surrounding space several times as great. During the day this wonderful machine sits idle, occupying precious urban real estate. Indeed, parking space in most cities has fallen far behind the demand. "Fringe parking," adopted by more cities each year, is the forerunner of quarantine. Traffic authorities would like to have quarantine now, banning private cars from downtown areas, but they know that near-total paralysis must set in before the public will accept it.

This automobile is a killer, too, because of its design as a free-moving vehicle controlled by its driver. Tens of thousands are killed and maimed by it each year.

What might the scientists and engineers conceive? They would not

be bound to roads and rails, the present division of duties among private automobiles, taxis, buses, trucks, trains, subways, and other earth-bound vehicles. But they would have to meet the enormously varied needs for transportation; hauling thousands of tons of coal from the mines to factories and homes; carrying mail; taking the family on a Sunday picnic; transporting a farmer and his crops to market.

Over heavily traveled routes, it is certain they would adopt the principle of canalized flow, for a single line of traffic, automatically timed and spaced, can carry much more volume, at higher speeds, than a superhighway. Within cities they would seek vehicles of minimum bulk and a system which would reduce their number by keeping them in service rather than standing idle.

Assume, for the sake of the argument, that they designed a wholly new system of vehicles, not a substitute for what we now have, or improved designs, but something utterly new in principle and operation. So different, in fact, that these vehicles could not operate on present highways or rails, nor could their pathways be installed without disrupting road and rail traffic. Perhaps between cities the new system could be constructed parallel to the old, but in congested metropolitan areas there is no room for such duplication.

Aside from such engineering difficulties, which might be solved somehow, could our economy stand the shock of change? Change would mean junking highways, automobile plants, garages, service stations, bridges, tunnels, and myriad other enterprises and structures.

In a climax forest, the more successful trees have crowded out all others. They have reached maturity, and their crowns, shading the entire forest floor, have helped check new growth. These giant trees cannot be replaced except by the beginning of a new cycle; they die or they are cut down, and new trees grow from seed.

It would be hasty to assume that a technical-economic system can reach this climax stage, its standards reaching an upper limit of development while, at the same time, preventing the introduction of new standards. Ingenious engineering solutions have been found to many problems of transition: replacing a bridge without interrupting the flow of traffic, for one. But the growing inertia of the standards of technical forms is a fact of modern civilization, as yet obscured by

the tremendous rate at which new standards have developed in the past half century.

Many such standards are now controlled by law. State laws limit the size and weight of highway vehicles, the design of headlights. The Federal Communications Commission decided which of two competing systems of color television should be licensed and has been considering whether to license subscription television. The Civil Aeronautics Administration, Interstate Commerce Commission, and Federal Power Commission have some standardizing powers.

The National Bureau of Standards has no "jurisdiction"; it is not a regulating or policing agency, even in weights and measures. But it is the source of many standards other than fundamental standards of measurement; data on physical constants and properties of materials; design of standard instruments, tests and analytic procedures; and standard samples. For example, Bureau research provided the foundations for the National Electrical Safety Code and other codes, national and local.

Screw threads were standardized years ago, but nation by nation. A British bolt could not be fitted with an American nut, a conflict of standards which was awkward and costly in wartime. In 1948 representatives of Canada, the United Kingdom and the United States met at the Bureau in Washington to sign an agreement on unification of screw thread standards. Fulfillment will take time, but some day American and British parts will be interchangeable. International standardization is a reality now for equipment used in drilling oil wells. Both achievements are engineering rather than diplomatic triumphs. Research showed how it could be done.

This is far more than the Congressmen had in mind when they cast their votes for Southard's bill in 1901. But while industrialization has demanded more and more from the nation's standardizing laboratory, Bureau leaders have set clear limits. They want no part in deciding the height of a hemline, the thickness of a slice of bread, or the length of a cigarette. The Bureau is for scientific standards; standards of style, convenience or policy are left to others.

10

THE ELECTRICAL CENTURY

President Theodore Roosevelt signed Southard's bill and appointed Samuel W. Stratton, former University of Chicago physics professor, as first director of the National Bureau of Standards. Stratton recruited a few aides, found temporary quarters, took over the work of the old Office of Weights and Measures, and then faced the formidable problem of what to do about building laboratories.

Today it would be routine: call in some architects and engineers; order equipment from scientific catalogs. But Stratton had no such resources; a laboratory like this had never been built in the United States. Few instruments were made in this country; that was one reason why the Bureau was needed. Nor could they be made to specifications in a country which had no adequate standards.

So, with preliminary work begun, Stratton and two aides sailed to Europe, where they visited the national physical laboratories of England and Germany and placed orders with European instrument-makers. The trip convinced them that instruments were the least of their concerns: "The facilities and appliances for carrying on an experiment under proper conditions are more difficult to secure than the apparatus itself," said Edward B. Rosa, Stratton's second in command.

Home again, they chose a site on Connecticut Avenue, three and a half miles from the White House, for the Bureau's home. Electric trolleys passed nearby, but not often, and the jarring of other traffic

was insignificant, for at the time there were but 25,000 automobiles in the entire United States.

This is still the Bureau's location, now expanded over 70 acres, resembling a large but unpretentious university. The present Director, Allen V. Astin, occupies Stratton's old office. But the city of Washington has swept around and far beyond the Bureau's grounds. Where Bureau scientists once picked blackberries on their way to work, there are apartment buildings and homes, whose residents are occasionally more than a little puzzled by their scientific neighbors, who once built a small frame house, set fire to it, and seemed surprised when the fire engines arrived.

What conditions had to be met in the new laboratories? It was easier to state them than to attain them. Some experiments would require rooms kept at constant temperature and humidity. But no commercial air-conditioning equipment was being manufactured then. Nor, for that matter, was information available on the insulating properties of building materials; that was something for the Bureau to provide in later years. The contractors who built the laboratories had an experience they never forgot. Part of one building was to be built without using nails or any ferrous metal. Windows were to be installed so they couldn't be opened. The basement of one building was filled with steam coils, refrigerating coils, and sheet-metal ducts, a primitive but effective air-conditioning system designed by the scientists—the architect feeling, as he often did on this job, like a bewildered bystander.

Construction was slow, in part because of planning difficulties, in part because of a local shortage of building materials. In temporary quarters, the Bureau's staff nucleus tried to keep up with the demand for services.

One night a Bureau technician, working late, had an alarming experience with non-standardization. A brush fire started and threatened one of the new buildings. Rushing out to fight it, he was dismayed to find that two lengths of fire hose couldn't be coupled together. Their fittings didn't match!

Two years later, in 1904, a $125 million fire ravaged a large section of nearby Baltimore. Fire engines rushed from surrounding cities and towns to help the Baltimore companies, only to find their hose

couplings wouldn't fit on Baltimore hydrants or couple with Baltimore hoses. The Bureau soon published a circular on the advantages of hose-coupling standardization, with suggestions for a national standard.

Thermometers made in the United States had been notoriously inaccurate. Now thermometer makers had a way of having their instruments certified, and they sent them to the Bureau by the hundreds. Many were rejected, sometimes nearly all in a batch. There began, then, the first of the collaborative activities which have since given aid to every division of industry. A thermometer was inaccurate. Why stop there? Perhaps the man making the tests was uniquely qualified to tell the maker *why* it was inaccurate. The faulty instruments were analyzed, and often a Bureau expert would go to the factory, examine the production process, and offer some informal suggestions that made the difference.

There was research to be done before even the basic standards could be used satisfactorily. The platinum meter bar, for example, had to be carefully preserved. It could not be taken from the vault whenever a comparison was to be made. For daily use there should be secondary standards, bars made of a less precious metal, better suited to frequent handling. Of course if they were made of a different alloy, they would have a different coefficient of expansion from the master bar. It would need study, but that brought up another difficulty! It was easy to say "alloy," but what did it mean? Metallurgists could analyze an alloy, but they had several analytical methods which often yielded different results. Before reliable data could be compiled on expansion, there had to be standard analytical methods.

Before long, too, someone should do something about a little matter the Office of Weights and Measures had never been able to handle: subdividing a length standard into equal parts.

There were, in fact, enough accumulated chores to keep a research staff busy for years. But there was also something new, so urgent and demanding that it was given priority even before ground was broken for the permanent laboratories.

The first central electric station had been put in service twenty years before, supplying a few hundred customers. Now almost three thousand generating plants were operating. The electrical industry

was booming and it desperately needed standards of measurement. The names of the units were agreed upon—the volt, watt, ampere, and so on—and their values fixed, theoretically. What industry had to have was instruments, reliable, accurate instruments, calibrated by dependable standards. And there were none in America.

It had been astonishing, the speed with which this new science developed, after so long a time. For centuries the magnetic attraction of lodestone for iron, and the attraction of rubbed amber for thread and paper, had excited mystical speculation. How old is the compass, a practical application of magnetism? A primitive lodestone compass was used in Persia five thousand years ago, to give direction to underground miners; and it may have been known in China even earlier. The Greeks were familiar with some of the phenomena of static electricity.

Willy Ley, the science writer and rocket expert, reported in 1939 the discovery of galvanic batteries used in Baghdad about the time of Christ! Willard F. M. Gray, a General Electric engineer, reproduced one of these batteries from Ley's description of the archeologist's find, and it worked.

Discovery is not enough to inaugurate a branch of science. Discoveries are often accidental, often made by men who have neither the training nor the curiosity to perceive their meaning. Some discoveries have been made time and again, and forgotten each time, until someone came along who did not dismiss it lightly, or attach the easy explanation of "magic." Science begins not with discovery, but with inquiry.

The compass was discovered and lost and rediscovered before it became, permanently, an instrument of navigation used by all civilized people. The batteries of Baghdad may never have been lost; some evidence suggests that the primitive method of goldplating used in Baghdad only fifty years ago had an almost uninterrupted history, the ancient batteries having been, always, a silversmiths' trade secret, and never more.

In Murray, Kentucky, a farmer-inventor, Nathan B. Stubblefield, gave public demonstrations of wireless transmission of voice and music three years before Marconi first sent code signals over a one mile distance in Italy! Stubblefield's apparatus was demonstrated in New

York and Philadelphia, and in Washington, D.C., where he made the first ship-to-shore radio broadcast from a boat anchored not far from Georgetown, in the Potomac River. The Wireless Telephone Company of America was incorporated, and a bill was introduced in Congress to install Stubblefield's wireless telephone in several major post offices. But Stubblefield, a secretive and suspicious man, let no one see inside his apparatus, and for years he refused to seek a patent. The promoters of the Wireless Telephone Company abandoned the venture; Stubblefield's apparatus mysteriously disappeared; and the inventor returned to Kentucky, isolating himself in a hillside cabin where he died of starvation in 1928.

The true path of science is a continuous chain of discovery, experimentation, inquiry; and the modern history of electricity begins in the 17th century when the first serious experiments were recorded.

The Leyden jar, a means of accumulating static electric charges, was invented in 1745. Some time later an English friend sent one to Benjamin Franklin. He began then the experiments which led to his discovery of the identity of static electricity and lightning, and his theory that there are two kinds of electricity, positive and negative. Volta invented the electrolytic battery in 1800—apparently without the aid of a Baghdad silversmith—and in 1802 the first electric light was exhibited, a piece of charcoal which gave off a brilliant spark when connected with a voltaic pile. A primitive electric telegraph was operated experimentally in Munich about 1805; its signal was a string of bubbles formed at the end of a wire immersed in water. Then, in 1820, Hans Christian Oersted made the epochal discovery that a magnetic needle is influenced by a wire carrying an electric current.

This discovery, made accidentally, aroused the interest of scientists everywhere. The needle's behavior refuted many past notions, giving proof of a relationship between magnetism and electricity. Oersted's discovery had such rapid consequences as to diminish his own place in history, for it stirred many experimenters into action, gave them a key, and the quick succession of their discoveries soon overshadowed his.

André Ampère conceived the rule that explained what Oersted

observed. He went on to show that two wires are attracted if their currents flow in the same direction, are repelled if they flow in opposite directions. He offered the revolutionary theory that magnetism is a manifestation of electric current.

The next step was taken by two men working independently: an Englishman, Michael Faraday, and an American, Joseph Henry. Some have debated the priority of their discoveries, but they themselves never did. Henry freely gave credit to Faraday for the first demonstration of induction, the use of a magnet to produce an electric current.

Henry was, in the opinion of many science historians, the first great man of science in the United States, the greatest American physical scientist of his century. He was notoriously slow in publishing the results of his experiments, and, indeed, there were few periodicals in which an American scientist could publish a paper in 1830, a handicap Henry did something about in later years. But he accepted the self-imposed principle of scientists that only publication establishes priority of discovery. When he did publish his own work on induced currents, he was careful to point out where Faraday had preceded him.

The principle of induction is shown in a simple classroom experiment. A coil of wire is wound around a hollow core and its ends connected to a sensitive meter which will be deflected by a small electric current. When a bar magnet is thrust into the core, the meter is deflected, returning to neutral when the motion ceases. When the magnet is pulled out of the core, the meter is deflected in the opposite direction, showing an opposite current.

It is easy to imagine fastening this bar magnet to the crankshaft of an engine, so that it moves back and forth through the core. The result is a flow of alternating current. Some of the mechanical energy of the engine is converted into electrical energy. Until this principle was discovered, there was only one known source of current electricity, the voltaic cell. Faraday and Henry showed the way to the power generator, the means of turning steam and water power into electric power. Henry was first to announce an almost equally important discovery. An electric current can be induced in a hollow coil by thrusting into it another coil in which an electric current is already flowing. Furthermore, if both coils are stationary, one within the other, a cur-

rent may be induced in one by a change in the value of the current flowing through the other. Henry also showed that the voltage of the induced current is in simple ratio to the number of turns in each coil: that a high-voltage low-amperage current can induce a low-voltage high-amperage current. This is the principle of the alternating-current transformer, which makes long-distance power transmission possible. It is also the principle of the direct-current spark coil, which, powered by a low-voltage battery, gives off a high-voltage spark. Such a spark coil was used by Marconi in his early wireless transmitter, and by Henry Ford, and other automobile makers, to provide the igniting spark in automobile engines.

While Samuel F. B. Morse was still pursuing his art studies in Europe, Joseph Henry built and demonstrated in 1831 the first practical electromagnetic telegraph. There is not the slightest doubt that he appreciated the significance of what he had done. He published his work, and declared that here was a principle which could readily be applied in commercial electric telegraphy. Indeed, he was of direct personal assistance to Morse, who patented the telegraph in 1837 and is generally credited with its invention.

Why didn't Henry apply for a patent, promote his discovery, and make a fortune? Judging from his record, he had too many other things to do. Commercialization of a patent is a career in itself. Henry had shown the way. Rather than spend years on development, he turned to other frontiers. He contributed to the development of the relay, a magnetic device through which a weak electric current controls a stronger one, an essential element in overland telegraphy, and with many other uses. He was first to use the earth as the return conductor in a circuit. He devised the first electromagnetic motor. He anticipated radio broadcasting by using one coil to induce a current in another a few feet away. He demonstrated that sunspots radiate less heat than other portions of the sun's surface. He developed a new method for measuring the velocity of projectiles. He wrote a paper which approached, but did not establish, a major law of science: the conservation of energy.

In 1846 Joseph Henry became the first secretary of the Smithsonian Institution. Under his guidance it became a force in the development of American science, stimulating research in neglected fields, provid-

ing scientists with their first adequate means of publication. He organized the first weather-reporting service in this country. He set up the first organized international exchange of scientific information. He conducted important research in fog signalling and helped to develop the lighthouse system. He directed the mobilization of scientific effort in the Civil War, and had a leading part in founding the American Association for the Advancement of Science and the National Academy of Sciences. In 1870 he represented the United States at the Paris meeting of the International Commission on the Meter.

Henry, Faraday, and their contemporaries, within a few short years, made the essential discoveries that opened the door to the general use of electricity. Here were the principles and the means of generating, transmitting, and applying electric energy. It took an astonishingly brief period to translate their discoveries into operating equipment. In 1882 the Pearl Street Station, first central power station, began service to a 12-block area in downtown New York City.

The experimenters had never seen electricity. It was an invisible phenomenon. They could only observe its effects, and to observe them they used instruments. The early instruments were qualitative; the information they provided was limited to "yes" and "no," or, perhaps, "more 'yes' than last time." A magnetized needle moved, or it didn't. A pointer was or was not deflected. Eventually it was necessary to ask the instruments another question: "How much?" Investigators were discovering that electrical phenomena had numerous characteristics, so the question was elaborated: "How much, and of what?" Research turned to measurement, and for measurement there had to be units, standards.

Magnetism could be measured by weight, relating it to the force of gravity, by loading weights into one pan of a scale until they equalled the force of a magnet applied to the other.

Electrical resistance was first measured in linear units. A Wheatstone bridge compared an unknown resistor with a standard resistor, a slide moving along a linear scale until the indicating needle was in equilibrium. This required a standard resistor, of course, and no two instruments would yield the same results until an accepted standard was available.

Voltage and amperage were observed by means of magnetic instruments, a current causing a pointer to swing across a dial, which was calibrated in linear units by comparison with a standard.

The mathematical relationship between the three principal units of electrical measurement was stated in Ohm's law, voltage = current times resistance. To the high school student who has wrestled with quadratic equations, this formula comes as a welcome relief. But it was not quite that simple, for the early experimenters.

The first need was terminology, agreeing to give the same name to the same thing. This was happily achieved at the International Electric Congress at Chicago in 1893. The next year the Congress of the United States, acting with rare promptness, legalized the new vocabulary of electrical measurement.

The Electrical Congress also adopted arbitrary definitions for each unit, basing them on the fundamental standards of measurement and known physical constants. The unit of resistance, the ohm, was defined as the resistance offered to an unvarying current by a column of mercury at the *temperature* of melting ice, 106.3 centimeters in *length,* of uniform cross-section, and of a *mass* of 14.4521 grams. The unit of current, the ampere, was defined as the unvarying current which would deposit metallic silver from a solution of silver nitrate at the rate of 0.001118 *grams* per *second.*

The Electrical Congress made one remarkable misstep, not the first in the history of measurement. It adopted specific definitions for all three units which are related in Ohm's law. The German physical laboratory soon discovered that the Congress' definition of the volt didn't agree with the value that could be computed by Ohm's law from the two other units. This led to some confusion, until the Electrical Congress of 1908 chose to retain the definitions of ohm and ampere, and to revise the definition of the volt.

This confusion was only one of the immediate problems the new National Bureau of Standards had to cope with. Industries, engineers and scientists had told Southard's committee about others. The plain fact was that despite past progress, the United States was well behind European countries in electrical research.

The Bureau's temporary quarters were on Capitol Hill, in an old

house on a site now occupied by the House of Representatives office building. Bedrooms once lit by gas mantles were soon crammed with work benches and apparatus. Cables ran through doorways and holes knocked into the plaster walls. This kind of hook-up would not have met the requirements of the safety code the Bureau later wrote!

Much had happened since the day, not so long before, when an official of the British Mint had told a Parliamentary Committee that he had no use for standards, the Mint's "reliable instrument maker" filling all its needs. The fixing of standards had become the most painstaking and exacting task of scientific research.

Suppose that you are an inspector in a machine shop which, at the moment, is making a propeller shaft. The buyer has been assured that his specified diameter will be met to within one one-thousandth of an inch. You are inspecting the shaft with a micrometer.

Your inspection finds points on the shaft which appear to be more than one one-thousandth of an inch over-size. But when the machinist is summoned, *his* micrometer says the shaft is within the specified tolerance. To settle this dispute, both micrometers must be checked against a working standard; your shop has one.

The faulty micrometer is adjusted; the shaft is reinspected and found satisfactory; and it is shipped to the buyer. But he promptly protests that according to his micrometers, checked against his working standard, the shaft has been turned down too much.

Both working standards are now suspect. This dispute can be settled only by having them certified. Certifying industrial standards is part of the Bureau's job.

From the fundamental standard, to the Bureau's working standard, to the machine shop's standard, to the inspector's instrument is three steps. Actually the chain is often longer, perhaps five or six steps.

None of the comparisons made is absolute; each is made within a range of accuracy, a certain tolerance. With each step away from the fundamental standard, the range broadens. If the original comparison is accurate to within 1 part in 100,000, for example, the second step in the chain of comparisons, even if made under equally good conditions, broadens the range to at least 2 parts in 100,000; in practice it is more than that.

A carpenter may be satisfied to work within a range of one-sixteenth of an inch. A machinist may want his work to be accurate to one ten-thousandths of an inch. If such precision is to be possible at the last step in the series, then the comparisons made at the first, in the National Bureau of Standards, must be accurate to one one-hundred-thousandth or even to one one-millionth of an inch.

The same rule applies to other kinds of measurement. A standardizing laboratory has an unbelievably complex and finicky assignment, for there is an almost endless list of conditions, known and unknown, which may subvert accuracy. Some conditions cause standards to "drift," changing slowly and almost imperceptibly over the years. Frequently variations will appear in a series of measurements, for no apparent reason, and it may take weeks or months to trace the cause. One of the men working in the old house on New Jersey Avenue was M. G. Lloyd, who told a meeting of engineers about some of the requirements he had to meet in electrical measurements:

> ". . . The mercury is introduced *in vacuo* in order to avoid bubbles or films of air. . . . This work is all done at the temperature of melting ice in order to avoid large corrections. . . . The glass used in these standards will be subject to the same changes which occur in thermometers, and it will be necessary to investigate the extent of this effect. . . . The objection to a coil of wire for a fundamental standard is that it is not reproducible, and moreover, no material has yet been found which can be used in this form without change. . . . If resistance comparisons are to be made to one part in a million, this requires that the temperature of the coil should be known to less than 0.005 degrees Centigrade and be kept constant within the same limits, a condition impossible to fulfill under ordinary working conditions. . . . Changes as great as 0.07 percent have been observed in one year. It is desirable that some better treatment than the present process of annealing be found for these coils. . . ."

Today the National Bureau of Standards can buy some of its equipment on the open market and have other items built to specification,

but even so occasionally it must build some of its own. In the beginning, it was even more dependent on its own resources, and a good shop man was as highly prized as an outstanding scientist. Indeed, the Bureau has had a few shop men whose ingenuity and skill was little short of genius. There was a time, for example, when there was need for wire drawn to a certain fineness with great precision. No such wire was manufactured commercially. Indeed, no one knew how to manufacture it. It could not be drawn through ordinary dies, and even diamond dies were not sufficiently regular. A scientist and a mechanic together invented a new method of drawing wire. Then they invented a method of winding the wire on coils with a degree of precision never before attained. When the paper reporting this work was published, the mechanic's name appeared as co-author.

Prior to World War I there were few instrument manufacturers in the United States. Today there are more than two thousand, with an annual output exceeding one billion dollars. Many of the instruments they produce were conceived and developed at the National Bureau of Standards or radically improved by Bureau men.

In 1910 the Bureau won international recognition; for in that year it was chosen as the site of the international project to resolve differences in electrical standards. Scientists of Germany, England and France arrived in Washington, bringing with them sets of high-quality working standards of resistance and voltage. In the Bureau's laboratories these standards and United States standards were compared, and agreement was reached on redefinition of the fundamental units. Within a year the four participating nations and many others had accepted the new definitions.

One early Bureau "first" was an invention which had commercial possibilities not realized for a quarter-century. The Bureau set up an exhibit at the Louisiana Purchase Exposition in St. Louis, in 1904. Seeking a way of making the exhibit attractive, the designers took a laboratory curiosity and applied it to the construction of a novel electric sign, with letters fashioned of glass tubing, glowing with a brilliant internal light quite different from that of the carbon filament lamps of the time. Thus was born the neon sign, not commercially produced until 1930.

In the fifty years since work began in the Bureau's first improvised workshop, the electrical industry has expanded fantastically, with so many aspects that it can no longer be segregated in national statistics. All industries use power. If electric power were cut off, every manufacturing plant in the United States, with few exceptions, would shut down. Every modern transportation device uses electricity for power, or for ignition and control. Accidents have on occasion blacked out major cities for a few hours, and the cities were virtually paralyzed until service was restored, with all lights out, elevators stalled between floors, signal systems inoperative, oil furnaces extinguished.

The first electrical instruments were used to measure electrical quantities. Today electricity has become itself a means of measurement; millions of electrical instruments are used to measure and record temperature, humidity, specific gravity, opacity, acidity, thickness, speed, time, and other qualities. The next step is automation. In the future electrically-operated instruments will not merely analyze and record; they will control and adjust the machinery of production. A few automatic factories have been built. In other plants, sections of the manufacturing process have been made automatic.

In 1902 the Bureau made less than two hundred tests of electrical instruments. For a few years thereafter the demands for testing and calibration rose sharply. Today most such tests are routine; they can be made by commercial laboratories, with occasional reference to the Bureau's standards. Shifting more testing work to private laboratories has been recommended by experts studying the Bureau, for it would free manpower and facilities for new research.

At the Bureau today, fifty men carry on the fundamental development of purely electrical standards. Three times that number are in specialized electronic research. At Boulder, Colorado, the radio division has about four hundred people. There were more than a thousand scientists, engineers and other specialists assigned to military projects, applications of electricity and electronics to proximity fuzes and guided missiles, but most of them, and their divisions, were transferred to the Department of Defense in 1953.

But just as the role of electricity in industry is not adequately described by Census data under "Electricity," so its role at the Bureau

is pervasive. In every laboratory, as in every industry and office, electricity has become so essential a tool and source of power that one can hardly imagine what things would be like without it.

Yet among the Bureau's senior scientists, there are some who learned to read and write by gas mantles and kerosene lamps.

11

FOR CONSUMERS AND CITIZENS

"THE FEDERAL GOVERNMENT, WHOSE OFFICIALS HAVE EXPRESSED MUCH solicitude for the ultimate consumer, possesses a vast store of useful information which it refuses to make available to the general public, because of a feeling that it would do great damage to business."

So a consumer spokesman declared in 1928, and he went on to quote an unnamed federal official, presumably of the National Bureau of Standards, "We would not last a week if we published the results of tests."

Could a scientific agency or its personnel be punished for allowing taxpayers to know the results of their laboratory work? It seemed so for a time in 1953. Over a number of years the Bureau had tested numerous battery additives and found they had no useful effect. The test results were published. The manufacturer of one additive, AD-X2, was aggrieved and set out to put political pressure on the Bureau to force a retraction. The new secretary of commerce, Sinclair Weeks, publicly repudiated the Bureau's work and demanded the resignation of director Allen V. Astin.

It was the first time a Bureau director had been fired because someone didn't like the findings of scientific tests, but the issue had come up time and time again: "Is the Bureau a consumer service agency? Should test results be published?"

Many consumers think the Bureau is a service agency, and dozens of letters each week ask for information about brand-name products.

Sometimes a manufacturer asks the Bureau to test his product, so he can advertise that it has been approved. Both are disappointed. The Bureau doesn't grade, rate, approve, or condemn brand-name products. When test results are published, brands are not named.

What about the charge that the Bureau has a vast store of useful information which it won't publish? It is true that the Bureau tests manufactured products. It has done so almost from the day it was founded. When Congress revised the Bureau's charter in 1950, it directed the Bureau to continue testing materials, supplies, and equipment at the request of government purchasing agencies.

Electric lamps were the first products tested. In 1904 the Bureau tested the elevator cables to be used in the Washington Monument, the cement for the new House of Representatives office building, and the adhesive power of mucilage for the Post Office. In the next few years there were tests of paper, twine, cloth, lubricating oils, varnish, paint, soap, ink, typewriter ribbons, carbon paper, rubber hose, gaskets, paving materials, cement, brick, and floor wax. Testing work expanded greatly in World War I, for the Bureau had the best-equipped laboratories to inspect war materiel: tent canvas, uniform cloth, saddle leather, and wheels for field artillery.

Indeed, it would be difficult to name a product, except for foods and drugs, which the Bureau has not tested. The list includes virtually every kind of item bought by the government: camera lenses, sutures, glass jars, shoes, hearing aids, rubber nipples, tires, and flashlight batteries, an almost endless catalog. So it is certainly true that the Bureau has a vast store of information. Most of it has never been published. But it is not necessarily true that this information would be useful to the consumer.

Government agencies buy by specification, not brand. They advertise their needs, giving technical specifications which bidders' products must meet. Sometimes bidders must submit samples to be tested. The government has the right to reject items which don't meet specifications. Often the Bureau helps a purchasing agent prepare specifications. He may also call on the Bureau to test samples.

As every federal employee knows, and sometimes complains, the government does not always buy top-quality merchandise. Government specifications do not describe the best products that can be manufac-

tured. They are minimums; they represent the lowest quality that will meet the need, or the best compromise between price and durability.

Government purchases are often very large, and bidding is highly competitive. If a manufacturer's usual product is superior to what the government wants, and therefore more expensive to make, he may lower his bid by lowering his quality, offering the government a product that barely meets its specifications, a product he will never distribute through retail outlets. Of course this is not true of all items. The government buys standard models of typewriters, automobiles, motion-picture projectors, electric fans, lawn mowers, and surgical instruments. It buys the same kind of aspirin sold in drugstores.

When the Bureau tests samples of products for a purchasing agency, it does not rank them in order of merit, nor does it designate one as "best." The tests are run to determine whether the products meet specifications. The product chosen by the purchasing agency is not necessarily the best; it is the one offered by the lowest bidder meeting the specifications.

Further, the only products tested are those submitted by companies that bid on government invitations. If a company doesn't bid, its product is not tested. So, while most *kinds* of products have been tested, the proportion of *brands* tested is much smaller. For example, the government buys shoes. There are about 1,500 shoe manufacturers in the nation, producing tens of thousands of styles. Only a few shoe companies are interested in making the kinds of shoes the government wants and the Bureau tests, chiefly military footwear. Such shoes are not worn by most civilians.

The needs of the government are often unlike the needs of the ordinary buyer. The Army may require that certain mechanical products be mildew- and fungus-proof. The government buyer usually has little interest in style, trim, and gadgets.

But after all of these exceptions and qualifications, there remains some truth in what the consumer spokesman said. In some cases the National Bureau of Standards does have information about brand-name products which would be useful to consumers; and it is Bureau policy to withhold such information from the public. Why? Is this sheer political expediency? Or is it sound public policy?

Suppose a government agency is buying paper towels. When the

samples submitted by the lowest bidder are tested, they fail to meet specifications. The samples submitted by the next higher bidder are approved.

Would it be proper for these facts to be published? The successful bidder could then advertise far and wide that his product had been "government approved." Perhaps thirty other companies make towels for commercial sale. Some didn't bid, so their towels weren't tested. The samples of some bidders may not have been tested because their bids were high. The consumer would have no information about the towels made by these companies, and some might be superior to the "government-approved" brand. Would it be good policy to give one manufacturer the enormous competitive advantage of thus advertising government approval? Would it be good policy to stigmatize another brand as disapproved, when many worse products may be on sale?

There is a further point. Product quality is not necessarily constant. Who could determine whether the product approved by the Bureau was the same as the product offered in stores six months later?

Bureau tests of brand-name products sometimes come to public attention in another way. If the Post Office is considering action against a product on grounds of mail fraud, it may ask the Bureau to test the product. The Bureau supplies the information desired. The Post Office decides then whether to make it public; and when there is prosecution the test results become part of the record. In the AD-X2 case, Bureau specialists were called to testify as expert witnesses.

Once consumer groups had the facts, the 1928 flurry died away, and the criticism has not been renewed. Quite apart from the political consequences, it is recognized that the Bureau policy of withholding brand-name information on test results makes sense.

Of course the Bureau publishes a tremendous amount of information, in pamphlets, technical journals, and books. Most of it is intended for the use of scientists, engineers, and technicians. Brand names are seldom mentioned, but this is not at issue. There is a great mass of information on the properties of such materials as cement, paints, lubricants, refrigerants, insulating materials, steel, leather, rubber.

These publications rarely give rise to controversy or criticism. But since the AD-X2 case, the very few Bureau publications addressed to consumer have been called into question.

The circular issued on battery additives named no names. But it was on public sale, and the consumer reading it might well decide not to buy battery additives. Another circular gave information on several types of automobile anti-freeze compounds, warning that two types are damaging to cooling systems. Circulars were also published on hearing aids, soldering, and control of odors.

An aftermath of the AD-X2 case was a decision that the Bureau Director should have responsibility in scientific matters, but that the Secretary of Commerce would decide on "non-technical procedures." The Secretary's decision seems to be that publishing information for consumers will be stopped.

"*Safety in the Household*," first published some years ago, is still on sale by the Superintendent of Documents at 75 cents. On the other hand, "*Care and Repair of the House*" is out of print; it will be revised and published by a commercial publishing house. Copies of the circular on battery additives were impounded at the Secretary's order and will probably not be released. The circular on automotive antifreezes is "out of print" and won't be reprinted.

The loss won't be great; there were only a few such publications of general interest, covering a tiny segment of the Bureau's work and an even smaller portion of the things consumers buy. It will not make Bureau men acutely unhappy to eliminate them. But this is a change in official thinking. In earlier days Bureau leaders thought consumer services should be promoted.

One early publication was a 150-page booklet on "Measurements for the Household." Many commodities now packaged were then sold in bulk, and the booklet urged the housewife to keep a set of weights and measures in the kitchen. It offered advice on how to detect the schemes of short-weight dealers. For example, she should beware of unusually low prices. It told her how to check a household thermometer (not a clinical thermometer): scrape a tumblerful of clear ice, saturate with ice-cold pure water; in this solution the instrument should read 32° F., within a tenth of a degree. It compared the cost of various means of illumination, at average prices. Highest cost: candles. With electricity at 10¢ per kilowatt hour, light from carbon-filament lamps cost seven times as much as gas-mantle light. Another comparison showed that hardwood was then the cheapest fuel for house

heating. Coal was twice as costly. Though it would cost ten times as much to heat a gallon of water by gas as by coal, the circular said the real advantage of coal was much less, since a gas fire, unlike a coal fire, could be turned on and off at will.

What was this new commodity, electricity, which householders were buying for the first time? What were they buying? The circular explained that electricity itself is not consumed; it merely flows through your lamps and back to the powerhouse. What you buy is energy.

> "A simple illustration will make this clear. Suppose a pump to be located in a central water-supply station to be operated so as to circulate water through pipes laid in the streets from which service pipes are run into buildings where power is needed. Assume that after the water has operated a water motor, it is not allowed to run into the sewers, but is taken back through return pipes to the pump, which sends it out again. In other words, the same water is circulated continuously, and gives up its energy by passing through a motor which can perform work.
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> "The customer of such a company would not be supplied with the water itself, but with the energy which the water possesses. This energy cannot be measured simply by measuring the number of gallons which have passed through the customer's motor in a given time, because the energy depends also on the difference in pressure between the inlet and outlet of the motor. . . ."

Another consumer guidebook was prepared during World War I, full of advice on the maintenance, use and repair of household materials and equipment.

How does an ice refrigerator work? To cool foods, heat must be absorbed. This is done by letting the foods supply heat to melt ice. Slow melting does not necessarily indicate a good refrigerator, for unless the ice melts it cannot absorb heat. Covering the ice is a good way to save ice but a poor way to save food. A chapter on white tableware explained the differences among American, English, and other china. But "it is to be hoped that the custom of buying European pottery, simply because of its foreign trade mark, will give way to a more pa-

triotic pride in American achievements and products." Did some housewife want to test the weather resistance of a brick? Bake it in the oven. Dunk in a Glauber's salt solution for twelve hours. Bake it again. Dunk it again. Repeat five times. If the brick shows no signs of cracks or crumbling, it's a fine brick. And the booklet also advised: "A fur coat is very much warmer if the fur is on the inside."

When these circulars were issued, America was scarcely a step away from home industries. In the recent past, soap, candles, yarn, fabrics, leather, sugar, wax, tallow, pens, ink, and other materials had been made at home. Now the factory was replacing these home products, and the Bureau circular declared: "Some social control over the quality and price of factory-made products is beginning to be felt through agencies such as the consumers' leagues, cooperative societies, publicity in the public press, misbranding laws, government control, and the like."

During World War I, the government urged a return to some of these old household trades. There was a campaign to put up canned foods at home. The Bureau tested rubber canning rings, found that many types on the market would fail in use, and worked with manufacturers to improve quality.

In the late 20's and early 30's, the consumer movement gathered strength, and the emphasis was on brand testing. Consumers' Research Inc. was established in 1931, to test branded products for its subscribers. The first technical director was a former Bureau physicist, F. J. Schlink. By 1940 the emphasis had shifted. Government and industry had both adopted the practice of buying on standard specifications. Why not develop similar specifications and branding requirements for consumer goods? A Bureau circular said:

> "The Bureau has done what it could to encourage the use of a procedure which would secure for the over-the-counter buyer the advantage of quality specifications similar to those which the Government utilizes . . . it has developed the labeling plan by means of which manufacturers are encouraged to identify by suitable labels such of their commodities as they are willing to guarantee as complying with certain nationally recognized standards or specifications. . . ."

There is a slight crusading flavor in the quotation, but this is exceptional in Bureau literature or in the public statements of Bureau directors. From the beginning the demands made on the Bureau have exceeded its resources; it has never had to seek new tasks. The Bureau leaders' philosophy has been to set as its boundaries the area of scientific investigation, and let others take responsibility for policy-making and enforcement.

Still, the Bureau is a tax-supported institution. Its annual budget is fixed by Congress, and Congress is notably more generous in appropriations to agencies which are well and favorably known to taxpayers. Director Astin, like his predecessors, must appear each year before Congressional appropriations committees, and he knows that public opinion has some effect on the decisions of the Members.

The Corps of Engineers, building dams, levees, and other structures, commands strong regional support. Most farmers have frequent contact with the United States Department of Agriculture. The Bureau has no such public reputation. Few citizens, even those who are generally well-informed, know the scope of the Bureau's work. Yet the fact is that few organizations, in government or out, have had a greater influence on modern living. The results of what the Bureau has done can be found in every garage, kitchen, basement, bathroom, in every factory, and in every office.

To take one small example, how many women know what the Bureau did about full-fashioned stockings? Some years ago the General Federation of Women's Clubs asked the Bureau to study the hosiery situation. Brand, price, appearance, and even construction were then quite unreliable guides to quality. In fact, what was quality and how could it be measured? Not even the manufacturers knew. The Bureau designed a testing machine. Manufacturers soon adopted it for their own use, and thus it became possible to draw up quality specifications. Then the industry, with Bureau help, got together and adopted standards for measuring size and length, eliminating the confusion which had prevailed.

This is a significant example, for it illustrates a point which early consumer campaigners often missed. The quality of a manufacturer's product is not necessarily within his control. Indeed, he may have no way of knowing what quality standards his products meet. To deter-

mine quality and control it, he must have means of testing, and testing can be, at times, a difficult and elusive problem. How does one test the wearing qualities of a pair of shoes? How can one measure the fire resistance of a sheet of wallboard? The acoustical properties of plaster? The lubricating properties of motor oil?

Performance testing is complicated by the diversity of conditions a finished product encounters. What determines the wearing qualities of a pair of shoes, for example? No two pairs will be subject to identical conditions of use.

It is easy enough to conceive tests. Shoe soles might be tested by abrading, flexing, and twisting. Some tests might be made after the shoes were wetted.

But the tests are not necessarily significant. Their findings may not permit reliable prediction of performance in actual use. As a matter of fact, after years of experimenting with "walking machines" and other methods, the Bureau has found no test of shoes quite as good as actual wear tests!

Devising a test is often easy. Validating a test can be extremely difficult. Even today one can find examples of tests being used in industry which have no demonstrable relationship to product performance.

Even when a significant test is found, findings are of dubious value until the test is standardized. There must be uniformity, so two laboratories testing the same material will reach similar conclusions.

Testing by manufacturers has done far more to improve quality than could ever be done by consumer testing. The reason is that consumer tests are of finished products; they rate or grade products. The manufacturer tests all along the line, beginning with raw materials and continuing through each processing step. Testing the finished product is pointless, from his point of view, unless he can also determine what went wrong and where. If adequate tests are devised, the manufacturer can set a quality standard for the finished product, then use raw materials tests and in-process tests to keep his production under control, so that the finished item meets his standard.

Materials testing is an essential requirement of mass production. Just as nonstandard parts would bring any assembly-line to a halt, so nonstandard materials would, in many cases, interrupt production.

Threads might snap under tension. Too-hard iron castings could cause excessive drill breakage. Such qualities as hardness, softness, resilience, elasticity, brittleness, and tensile strength can vary within only a limited range without causing production difficulties.

The American Society for Testing Materials was incorporated in 1902, soon after the Bureau was founded. Its members are producers, consumers, scientists, and engineers; its purposes are the promotion of knowledge of the materials of engineering, and the standardization of specifications and testing methods. Members of the National Bureau of Standards staff today hold more than four hundred positions on A.S.T.M. committees.

Consumer testing can be done more or less at leisure. To test a brand of automobile tires, for example, one could install samples on a fleet of test cars and drive the cars 25,000 miles over all kinds of roads.

Such a test has almost no value in controlling a manufacturing process. In a mass-production industry, there is need for tests which can be made within minutes, not days or months. In making automobile tires one of the first steps is mixing the rubber compound for the carcass. Samples of the compound are taken as the material comes from the mixer, and sent to the laboratory for analysis.

Meanwhile, the manufacturing process must continue. Suppose that laboratory tests of the rubber show that something went wrong in the mixer, but the test results are not available for four hours. If the fault is beyond permissible limits, the off-standard materials, now well along in the manufacturing process, must be scrapped or reprocessed. The longer the delay, the greater the loss.

No manufacturer can afford to throw away half a day's production, at least not very often. Until he has testing methods which permit tighter control, he will market products which are not of uniform quality.

Bureau research and testing development has been directly responsible for improvement in the quality of hundreds of products, from silk stockings to amalgam fillings in teeth, from motor oils to bathroom fixtures. Testing has resulted in better quality, and also in lower prices. But neither the average consumer nor the average Congressman knows about it. Nor, for that matter, does the average consumer know what the Bureau has done to protect his life. He rides in

elevators, drives over concrete bridges, cooks on an electric stove powered by more-than-lethal current. The Bureau devised the basic elevator safety tests. The bridge designer used Bureau data to calculate its strength. The Bureau compiled the National Electrical Safety Code.

Around 1923 people were aroused by the large number of highway deaths caused by automobile brake failures. Bills were introduced in state legislatures requiring that cars have "adequate brakes." But what were adequate brakes? No one knew. The Bureau and the American Automobile Association called a conference of industry, state, and association representatives. The members adopted a standard safety code, based on Bureau research, which became a model for state legislatures. The Bureau also had a hand in developing brake-testing devices. A few years later headlights demanded attention. What were "safe and adequate" headlights? Again Bureau research set the pattern for state codes.

The man who devises a test is seldom content to observe what happens. He wants to know why. There is no sharp line between product testing and product development; one often leads to the other. A few years ago the American ceramic industry was harassed by a chronic problem, affecting tableware and wall tile. No matter how carefully they were processed and cared for, they might "craze" after a few months in use. The cause of the crazing was unknown, and the cost was high. Customers were turning to imported products. Ceramists at the Bureau, with industry cooperation, went to work on the problem. Some kind of test was needed which would predict whether a batch of tile would craze. They found the test. But at the same time they discovered the source of the difficulty and how to remedy it. Before long consumers were able to buy ceramic products guaranteed not to craze.

Though the Bureau doesn't make tests for consumers, there is no secret about Bureau testing procedures, and Bureau men cooperate with the technical staffs of such testing organizations as Consumers Union. Since Consumers Union is financed by membership fees, it is not subject to political pressures. Members, in an annual poll, decide what products shall be tested. The annual membership fee is no

greater than what a consumer would have to pay for government pamphlets on the same range of subjects, were they published.

Consumer testing, especially on such an independent basis, has a logical place in the commercial scheme, because no manufacturer is compelled to test his product or, in most cases, to meet specifications. Large retail organizations are often specification buyers; they insist that suppliers meet their standards; but even they do not sell to consumers by specification.

The clinical thermometer you buy in a drug store has not been tested and certified by the National Bureau of Standards. If the manufacturer of that thermometer wants his standard instruments checked, he can send them to the Bureau, but he is not compelled to do so. There is a federal standard specification for clinical thermometers, but unless a company is selling them to the government or to a large buyer who insists they meet specifications, they need not do so. Of course, if the company advertises that its products meet this specification, it assumes a responsibility, but voluntarily. Recently Consumers Union tested clinical thermometers for its members, buying samples of several brands on the open market. Most of the samples were found to meet the standard specification. But several samples of one well-known brand were found to be substantially inaccurate.

Quite apart from political and administrative considerations, there is another reason why Bureau men want to avoid consumer testing. Most of the Bureau's testing projects come to an end when methods and instruments have been developed. This is research. There has never been more than a small fraction of the Bureau staff assigned to testing, yet hardly an industry has not benefited.

When Consumers Union tested thermometers, it did not test every brand on the market. A government testing agency could not be as selective, nor could it justify testing one class of products and not another. In short, it would take on an endless task of routine testing, endless because of the hundreds of thousands of new brands, models, styles, and qualities placed on the market each year. A Bureau division chief once estimated that it would take 50,000 technicians to do the work.

As the policy has operated, consumers buy hundreds of products which have been tested not by the Bureau but by Bureau-developed

methods. The list includes dress fabrics, plate and sheet glass, carpets, silver-plated tableware, waterproofing compounds, window sash cord, vitreous enamelware, gloves, dry-cleaning solvents, shoes, soaps and detergents, floor polishes, garden hose, wall and floor tile, brick, cement—in fact most building materials—hand luggage, fire-extinguishers, electrical apparatus, rubber products, and many more.

Test development has meant close cooperation with industry, and because of the Bureau's facilities it is often called on to solve some technical mysteries. Offset printers once appealed for help. They were suffering heavy losses because of misregistration of successive color prints. A bureau paper expert cracked the case: changes in moisture content were causing the paper to expand and contract. He showed the printers how to eliminate the problem, too.

Housewives and textile makers once had a problem. They sent in samples of cotton fabrics which had apparently rotted, and for no apparent reason. It happened in winter-time, when they were hung outdoors on the washline. The answer was found in a test-tube: sulfuric acid. Sulfur dioxide was being emitted in smoke from nearby chimneys; in the damp fabric it formed sulfuric acid. The remedy: a little calcium carbonate in the final rinse water.

Today we assume railroad trains will stay on their tracks, but rail travel was not always so safe. Once, about 1912, a serious wreck was traced to a broken rail. Interstate Commerce Commission investigators shipped the rail to the Bureau, where metallurgists soon found why this particular rail had failed. Was the flaw characteristic? Other broken rails were assembled for study, and Bureau scientists traced the trouble back to a processing step in the steel mills. Stronger, safer rails were soon being made.

When a steamboat exploded, a Steamboat Inspection Service trouble-shooter found in the wreckage the one item that *shouldn't* have been intact: the boiler safety plug, which should have melted. What happened? The answer came from a Bureau laboratory: a chemical change had raised the melting point of the plug. The Bureau also recommended an alloy which would keep a low melting point.

In 1922 the steel-and-concrete roof of the Knickerbocker Theater in Washington, D. C., collapsed under a moderate snow load, causing nearly a hundred deaths. Within a few years of this time several sup-

posedly fireproof buildings had collapsed during fires, when steel girders failed. A new aqueduct bringing water to New York City crumbled. A concrete bridge gave way, dropping the driver and a wagon-load of lumber into the river below. A new highway disintegrated soon after it was built.

State and local governments were trying to forestall such disasters, but with little success. Architects and contractors were often blamed, without much evidence. There were no standards defining safe construction, nor did architects and engineers have reliable information on the strength of materials. How, in technical terms, did one define a bridge that wouldn't fall down?

Bureau men went to the scenes of failures and brought back samples for study. The theater roof collapsed because the concrete had frozen before setting, they found, and, in any case, the design was inadequate. Steel girders in burning buildings had crumpled because they were not sufficiently insulated against heat.

Disasters were duplicated in miniature. New testing machines were set up at the Bureau, including compression devices which could bend a steel girder or crush a concrete column. Once, to find out what happens inside a burning building, Bureau scientists obtained permission to burn a condemned six-story structure in the heart of downtown Washington. Month by month the data accumulated, information on the properties of steel, concrete, wire cables, brick, and other materials. On this foundation of fact, towns and cities adopted building codes, elevator safety codes, plumbing codes, gas safety codes.

There is no end to such research, for each year new materials are introduced, and new demands on materials arise. Recently the Bureau has been testing a lightweight concrete, so light a chunk will float on water. Ceramists are seeking materials which will withstand higher temperatures. In the Bureau's testing laboratories one may see a piece of an airplane wing that failed, or a ship's plate.

A fighter plane pulls out of a power dive, putting its wings under tremendous stress, but it lands safely and there is no outward sign of damage. Yet if the wings were stressed beyond a safe limit, they may fail on the next flight. A glance at a tiny device under each wing tells mechanics what happened. It's a load-limit gage designed at the Bureau, a simple arrangement of arm, cam, and gage points. The arm is

cocked. If it flips past the cam, the wing has been overstressed and the plane goes in for overhaul.

Metal airplane parts may fail for another reason: accumulated fatigue. For months or years they may withstand the stresses of rough weather and landings. But slow, invisible changes are occurring in the crystalline structure of the metal. Some day, even under moderate load, there may be a failure. How can such failures be predicted? Multi-million dollar airliners can't be grounded by guesswork. Part of the answer is another Bureau device which keeps a permanent record of every bump experienced in flight. Another part is a bit of wire designed to break before the structure fails. Specimens of the metals used in aircraft are sent to the Bureau, where testing machines subject them to accelerated life tests. From laboratory failures, the safe life of plane components can be predicted.

The next elevator you ride in may fall, or your office building may collapse, or a bridge may give way when you drive over it. If so, don't blame the National Bureau of Standards. The Bureau neither makes nor enforces safety regulations.

Perhaps the building code of your city is out of date. Perhaps the building inspectors are lax, or corrupt. A few concrete suppliers add too much water to the mix, because it's easier to pour that way. A few months ago a school building collapsed, killing several children, thanks to a contractor who knew sand was cheaper than cement. Many building codes err in the other direction. They have not been revised to permit the use of new, lighter, higher-strength materials. Construction under those codes is safe enough, but it is needlessly expensive. These are problems to be settled in the voting booth, not in the laboratory.

If you write to the Bureau asking a technical question, the chances are that you will receive a polite answer, and perhaps the information you want, too. That is, unless you're asking for information about branded products, or unless you ask the kind of question which comes in the Bureau's mail occasionally: "Please send me everything you have." Or "Please tell me all about perpetual motion."

But, to be quite frank about it, the Bureau wishes you wouldn't write. Congress hasn't provided any money to support such a service.

More than ninety percent of the answerable questions asked in such letters can be answered by any good library. Time spent by the Bureau in answering such letters is time taken away from research.

On the other hand, top officials of the National Bureau of Standards know that science in government must have public support, and that public support requires that people know what's going on. They don't want to slam the door. Indeed, they wish it could be opened wider. In years gone by, thousands of high school students, when they visited Washington, were taken on tours of the Bureau. War-time security rules put a stop to that, and since the war there hasn't been time or money or personnel to start the tours again. It's a serious public relations problem, and no one has yet come up with the right answer.

12

THE INDISPENSABLE WARRIOR

THE NATIONAL BUREAU OF STANDARDS HAS PRESERVED THE CONSTITUTION of the United States, and the Declaration of Independence, too. Both documents were showing signs of age, and it seemed that they would have to be sealed in a dark, airless vault for protection. But visitors to Washington want to see them, the originals, not copies, with John Hancock's signature still showing the impress of his pen.

Today visitors can see them both on display at the National Archives, visible but immune to the passage of time. Both are sealed in Bureau-designed cases, helium-filled to exclude oxygen, faced with a glass that filters out harmful violet and ultraviolet light.

Citizens and Congressmen sometimes wonder why the nation's standardizing laboratory is such a prolific source of gadgets and inventions. What have standards to do with, say, a money-counting machine? The Bureau invented this one for the Treasury Department. Every day about five million worn-out one-dollar bills are returned to the Treasury, cancelled by punching and cut in half. They have to be counted, and the count has to be right.

Counting a number of uniform objects is not usually a difficult engineering problem, but old bills are limp, wrinkled, torn, patched with gummed tape. The machine used to count new bills had a nervous breakdown when it was asked to run through stacks of old money.

The Bureau's electronic instrument specialists made several false starts. Their first idea was to scan the side of a packet of bills with a

thin light beam, and count the dark lines by reflections into a phototube. It didn't work; irregularities were too great. The final solution they considered "less elegant," but it worked. Packets of bills are firmly stapled at one end, and the other end is cut square. The stack is wrapped around a spindle, which pulls the ends slightly apart. The spindle is turned, and bills are released one by one as the ends pass under a friction band. As each is released, a jet of air flips it across the path of a light beam. Interruptions of the beam are counted electronically. The machine counts 30,000 bills per hour.

Another fast-moving machine developed for the Treasury weighs new coins to make sure they are neither too light nor too heavy. Though each coin is weighed in one-fifth of a second while it is whirled by a flywheel spinning at 3,000 revolutions per minute, weighing is accurate to a quarter of one percent.

In fifty years the Bureau has fathered hundreds of such devices, from the simple strain gage, which has no moving parts, to some of the most complex and formidable weapons in the national arsenal. The contrast between basic research and mechanical invention seems great, if one thinks of a research scientists as an impractical fellow peering through a microscope, a chap who knows all about electrons but couldn't repair a doorbell.

The fact is, a scientist is likely to be severely handicapped if he isn't a competent mechanic, too. Much of the apparatus used in pioneer investigations is unique. Indeed, being able to conceive, design and build apparatus which will perform in a certain way is at times the essential part of an investigation. Once the apparatus has been built, using it is almost routine. This is why the Bureau has an excellent machine shop, and why some men who are credited with major achievements at the Bureau were trained as machinists and mechanics rather than as scientists. Much of the Bureau's equipment was Bureau-designed and built, and it includes some of the world's most precise apparatus.

The Treasury and other federal agencies have often called on the Bureau for help, because of these special skills. But it was Germany's unrestricted submarine warfare, bringing the United States into World War I, that gave a new shape to the Bureau's work. When we entered the war, the entire Army had less than eighty qualified air-

plane pilots. When the Armistice was signed, the air force had more than twenty thousand officers and more than 160,000 enlisted men, plus hundreds of cadets.

When the war began, the United States had fallen far behind European nations in aircraft development, civilian as well as military. The planes in use by this country were clumsy, their engines heavy and undependable. Accidents caused more casualties than the enemy. There was a desperate race to catch up, in construction of planes, training of pilots, and in operating methods. Operating called for better instruments, and the United States had little instrument knowledge or manufacturing capacity. The best available and best-equipped instrument laboratory was at the Bureau. Using European instruments as models, the Bureau put groups at work, day and night, to see what could be done.

There wasn't time to do everything. Many projects began as investigations of failures. When one type of altimeter failed repeatedly, the Bureau traced the cause to a small steel chain, which rusted; 5,000 instruments, already accepted by the air service, were called back for modification.

Airborne wireless was still a novel idea, and weather was the pilot's worst enemy. But a story in the Washington *Star* on August 24, 1919 gave a hint of things to come:

> "Somewhere on the Western Front pilot Harold Black, A.E.F., was soaring above the shelter of concealing clouds with a crippled airplane, trying to find his way back to a landing place and safety.
>
> "As he circled in a maze, vainly hoping for aid of some sort before his supply of gasoline was totally consumed, he succeeded in bringing the coil aerial detection finder and other parts of the radio to life.
>
> " 'Beer Zed—Beer Zed!' they called insistently.
>
> "It was the signal call from the landing station.
>
> "Turning until he reached a position at which the signals were strongest, Pilot Black headed in that direction. . . .
>
> "Warily, for he had left four German planes in his rear and below him, he headed the airplane for home. The moment he dropped below the clouds he saw a sight that caused him to rise

quickly. Only a few miles behind, unharmed, were three of his former adversaries, careening in lazy indifference in their safety from opposing barrages.

"Within half an hour a heavy mist had risen, and Pilot Black knew that he was safe. The German planes would not have remained up in such weather. But the very condition that provided immunity from hostile attack made his landing a precarious matter. Once more, guiding himself by the intensity of his radio signals, he directed the machine to the landing area.

"Inevitably, through the dangers and darkness of fog and night the direction finder showed him the course, until he could sight the landing field. Gracefully and as uneventfully as if it had been a broad daylight landing, Pilot Black and his machine came to rest on terra firma. The adventure was over."

The direction finder was not an altogether new device, said the *Star*:

> "Long before the war Germany and other countries had adopted the use of coils for receiving radios in military usage. It remained for the Bureau of Standards, however, patiently to perfect and point the way to the military departments of this government."

Dr. F. A. Kolster of the Bureau is credited with development of the direction finder between 1913 and 1915. It was crude, and today the hardiest bush pilot would choose his parachute rather than try landing by it. But it was a beginning, and in 1931 Harry Diamond, Bureau scientist, and Marshall S. Boggs, test pilot, made the first flight tests of a better system.

Francis Dunmore and a colleague, F. H. Engel, began the work on this system, seeking to improve the direction-finding coil, and developing a directional radio beacon. After Diamond joined the Bureau staff, he and Dunmore moved the project headquarters from the Bureau to a small field at College Park, Maryland. It was only a rough pasture, and they paid a farmer ten dollars to chop down a tree in the middle of the "runway." They could do nothing about a nearby chimney,

which had to be cleared by no more than eight feet to make a good landing.

A single radio beacon can serve as a homing signal, which a pilot follows to bring him close to his port. But then he faces the problem of landing, a three-dimensional problem. To land blind, he needs lateral, longitudinal, and horizontal guidance. On September 5, 1931, Boggs made the first blind landing in history using radio signals for all three kinds of information. Circling far from the field, he picked up the range beacon and followed it until he heard the "over tower" signal in his headphones. Then he switched to the frequency bands of the new system. Banking, he turned until a needle on the new instrument flickered, the signal of the radio path. He picked up the path four miles away, leveled off, and gave his full attention to the instrument. It had two needles, one horizontal, one vertical. If the horizontal needle was deflected downward, he was below the proper glide path. Deflection of the vertical needle showed his deviation to the right or left of the path.

Boggs deliberately changed course a few times to check the instrument, decided it was operating properly, and followed the course it marked. At 2,000 feet from the field a light blinked on the panel; he had passed the first marker beacon. A minute later it blinked again; that was the airport boundary. Five seconds later his wheels touched down.

This was the beginning of the Diamond-Dunmore Instrument Landing System, now one of aviation's standard safety devices. With the development of radar, another blind landing system, Ground Control Approach, was introduced, and pilots divided into factions, some preferring ILS, some GCA. Many airports offer both, and some experts like the two in combination: the pilot controlling his landing by ILS, while a ground observer monitors his approach on the GCA radar screen.

The airplane had the lion's share of scientific attention in World War I. Bureau history tells an odd story of research in construction. The airplane was then a wood-and-canvas affair. The preferred wood was spruce, and war needs put such pressure on supply that prices soared. A project was set up to seek a substitute for spruce.

Could some kind of metal be used for the airframe? Steel was considered and rejected as too heavy. Aluminum seemed to have some promise. In cooperation with an aircraft company, the Bureau built an experimental all-metal plane, which was not considered airworthy. An aluminum-frame aircraft was test-flown, but the war ended before conclusively good results were achieved.

The Bureau's aeronautical engineers were apparently not convinced, judging by their published reports, that all-metal planes were practical. They liked metal for frames, but said they hoped to find "a covering which will be not only fireproof, but transparent as well."

The first aerial duels in World War I were fought with pistols and rifles. Large aircraft were soon equipped with swivel-mounted machine guns. For fighter planes, the need was a machine gun which could be aimed by aiming the plane, and the best position was directly behind the propeller. In 1918 members of one Bureau group were working the bugs out of synchronizing mechanisms, intended to shoot through the moving blades without shooting them off.

Both sides were using balloons, inflated with hydrogen, a gas readily ignited by incendiary bullets. The United States was beginning production of helium, a noninflammable gas, but supply was small. The Bureau developed an improved field unit to generate hydrogen and experimented with hydrogen-helium mixtures to determine how the new gas could be used best.

Almost every division of the Bureau had some tasks in aeronautical research, urgent searches for better fuels, engine components, instruments, safety devices, canvas dopes, landing gear, and signalling devices. The pressure was intense and some of the best results came from informal unrecorded meetings, convened hastily when a worried air officer dashed out to the Bureau in search of a new attack on a problem.

Military men had good reason to worry, for the United States had lagged far behind in some branches of science and technology, notably communications. There were reports that German ships were dragging grapples along the ocean bottom, hoping to find and cut transatlantic cables. That put a high priority on reliable transoceanic radio transmission. The Navy wanted a means of broadcasting to and from submerged submarines. Ground forces wanted portable radio ap-

paratus. Morse code wasn't satisfactory for some purposes; radio telephony would be far better—and European countries already had it. All of this called for something better than spark-gap transmitters.

The something better was known. The basic discovery had been made by an American. Thomas Edison had over a thousand patents, but he is credited with only one scientific discovery: the "Edison effect." Like the Baghdad silversmith with the galvanic battery, he never explained the effect, never had time to study it, and failed to grasp its significance. Experimenting with carbon-filament electric lamps, Edison found that too high a voltage would vaporize the filament, blackening the inside of the glass bulb. But he noticed a clear streak, a "shadow," in the blackening, apparently cast by one side of the filament.

Edison placed a metal plate between the two legs of the filament and connected it to a sensitive galvanometer. When he connected the other terminal of the galvanometer to the positive terminal of the lamp, he found a small current flowing. But it was a one-way current; nothing happened when he tried the negative terminal of the lamp. He made this discovery in 1884. Twenty years later, Ambrose Fleming, in England, patented the "thermionic valve." Lee De Forest, in America, added the third element, the grid, and the modern electron tube was born.

But when World War I began, American military men knew next to nothing about electron tubes and their significance in wireless communication. They were frankly amazed when a French scientific mission arrived in 1917 and, at the National Bureau of Standards, demonstrated military communications equipment far superior to anything the Americans had ever seen, using vacuum tubes. The Signal Corps was given the task of developing military equipment. The Bureau was responsible for standardizing tube design, specifications, and tests.

Radio and the airplane were the big science stories of World War I, though the automobile was still new enough to be a novelty. But while staff groups at the Bureau were pushing forward on major research projects, trying to achieve long-range results in a year or two, there was also a daily influx of spot problems. An urgent call came from the trenches: "Give us something so we can hear German sap-

pers!" A few weeks later the Bureau gave the Army a "geophone," which would detect and amplify sounds transmitted through the earth. "How can we detect a periscope on a sunny ocean?" The best answer was a pair of goggles, fitted with filters and light shields to minimize the dazzle.

Bureau men worked on designs for concrete ships, protective fence lighting, identification tags. There was work to be done on electric storage batteries, motor fuels, explosives, tanning agents, shell cases, photographic film, rubber tires. The Army found many flaws in rifle barrels, until Bureau metallurgists traced them to a step in the process of steel making. Supplies of optical glass had been cut off by the war. No domestic source could meet the need. The Bureau built and operated its own optical glass factory, and maintained it until World War II, when it was needed again.

The scientist had little difficulty with his conscience in World War I. True, science was mobilized and war needs had top priority. But little of the scientific work had to do with the design of weapons, as such. In aeronautics, electronics, optics, chemistry, instrumentation, engineering, the problems were not very different from those of peacetime and civilian applications. The effect of war was to pour money into research, to accelerate what had been going on before, and there was no question but that the work would have peacetime value.

Ten or twenty years of development were crowded into two. Before the war ended, radio communication was in general military use. In 1920 modern commercial broadcasting began, when KDKA in Pittsburgh reported the returns in the Harding-Cox Presidential election. By 1920 automobile registrations had soared to more than eight million. Eight times as many motor buses and trucks were in use as in 1915. Boys who once dreamed of going to sea now wanted to be radio operators or airplane pilots.

The war also made a significant change in the pattern of American scientific research: the new industries, such as electronics, set up laboratories of their own, and older industries were also becoming research-minded. By 1930, two thirds of the nation's research was industry-supported, a proportion maintained through the years of

economic depression. Indeed, dollar expenditures for research had been doubled by 1940.

Though the work of the National Bureau of Standards broadened in these years, its general objectives were the same as before. Industry and science needed higher precision in measurement. New units of measurement had to be studied and standardized: radiation, sound absorption, color, hardness, resilience. New testing machines and devices were set up: a wind tunnel, an altitude chamber.

Tests for automobile brakes, headlights, engines and lubricants were developed. Radio engineers needed a way of describing, mathematically, the performance of antennae. The broadcasting industry needed radio frequency standards. Electrical measurement was pushed upwards to 250,000 volts.

No federal agency has been so intimately associated with industry as the Bureau, and none less subject to charges of "government competition with private business." And this despite the fact that hundreds of private industrial research laboratories were set up in the years after World War I. There were more than two thousand of them by 1940, and the dividing line between what they do and what the Bureau does is not sharp.

Somehow an understanding has grown which transcends formal policy. Generally, the Bureau avoids industrial development work. But in some cases Bureau facilities are unique and it would be impractical for another laboratory to duplicate them. In others the Bureau has special know-how. More important, some projects called for joint efforts, neither government nor private resources alone being sufficient.

The Research Associate plan was one sensible solution. Some research men, hired and paid by industry, work at the Bureau side by side with Bureau men. The Portland Cement Association has maintained research associates at the Bureau for more than thirty years. One of the first products of this joint research was a quick-setting cement, permitting a new highway to be opened seven hours after concrete was poured. The group developed the cements used in Boulder Dam. Since the associate plan was initiated in 1919, close to two hundred industry groups have participated. Five years after it began, a committee of scientists and businessmen was appointed to appraise it.

Joint motor-fuel investigations had saved industry and the public

$100 million a year, the committee reported. Tire investigations had saved $40 million a year, brake-lining studies $15 million. Research on elevator interlocks had improved safety conditions so that insurance companies had reduced annual liability premiums by half a million dollars. The textile industry put a value of $28 million a year on the results of their associates' work at the Bureau.

This was the Bureau in 1941. World War I broadened its work, gave it new laboratories and programs for applied research and development. In that war the demands on science were not so much for weaponry as for accelerated progress in aeronautics, communications, instruments and materials testing. Wartime research gave impetus to peacetime industry. Peacetime research in the years following was an extension of all that had gone before.

The first eleven months of 1941 were like those of any other year on the Bureau's quiet campus. An eclipse expedition was sponsored jointly with the National Geographic Society, and Bureau men designed two corona cameras and two large spectrographs. Delegates from 28 states attended the Thirty-First Annual Conference on Weights and Measures in Washington. A new high-voltage laboratory was nearing completion. An automatic system of Geiger counters was designed—to study cosmic rays; the system was installed aboard the schooner *Morrisey* of the Louise A. Boyd Arctic Expedition.

A few defense projects were under way, but they were not mentioned in that year's annual report. There was, in fact, only one reference to the world situation and the war going on in Europe:

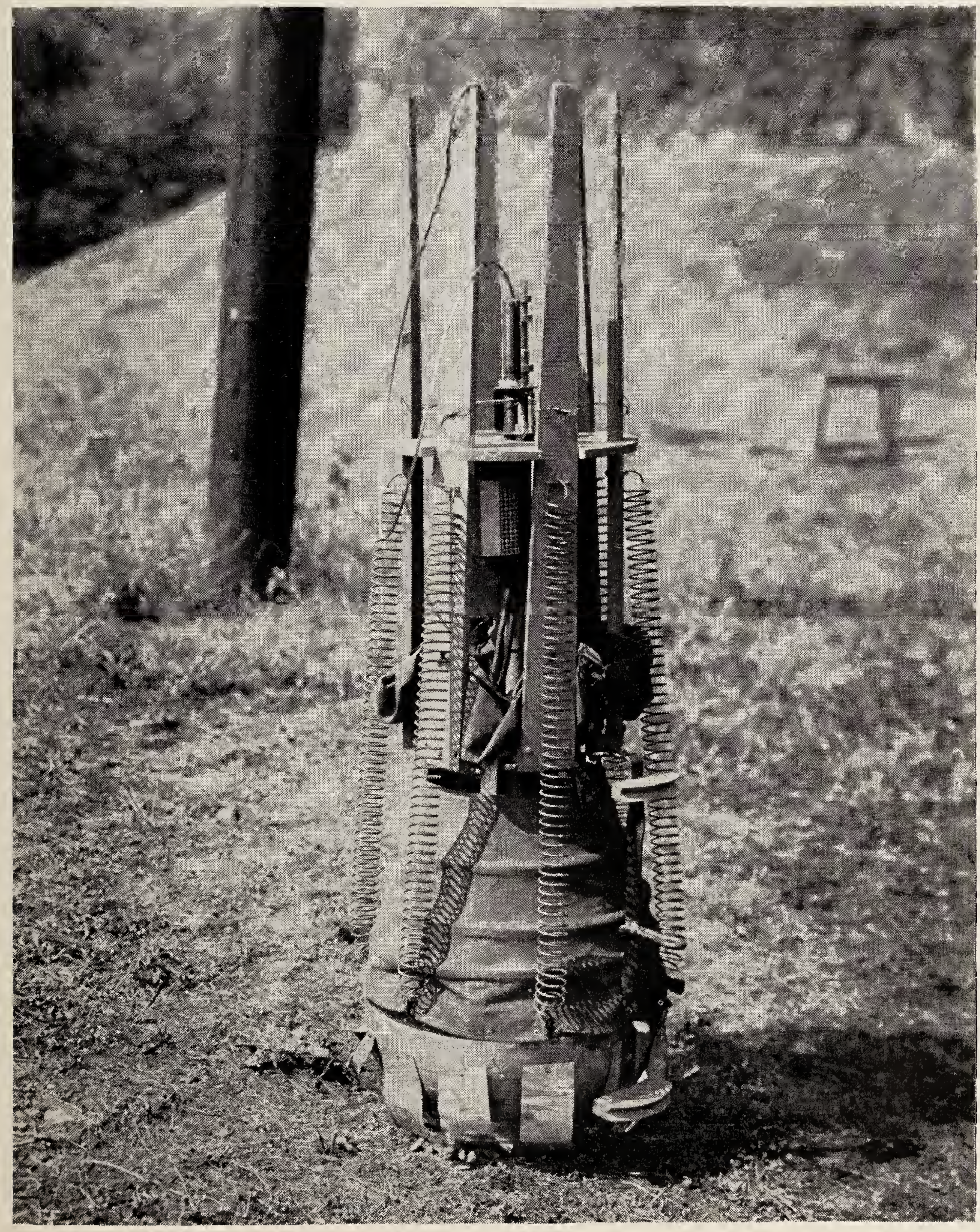
> "Since international action on the readjustment of electrical units has been indefinitely delayed, the Bureau is bringing to a close its researches on absolute measurement of current and resistance."

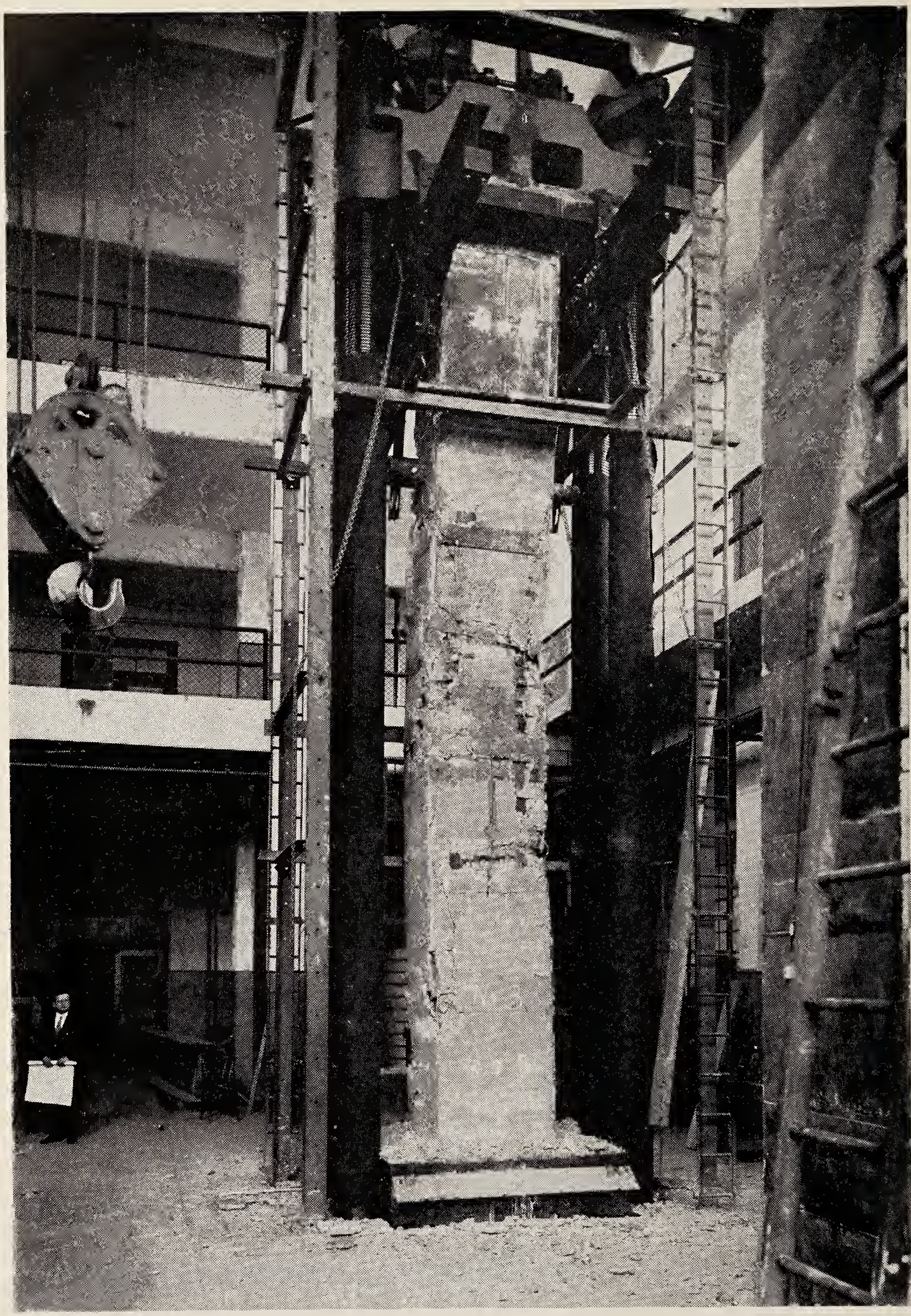
It was a fine Sunday afternoon in Washington on December 7th, and many of the Bureau's men were listening to the symphony, when the news flash came through from Pearl Harbor.

When war came, it was like nothing that had ever happened before, and it brought to an end the fullest, richest chapter yet written in the history of science. Things would never be quite the same again, at the Bureau or in any university or industrial laboratory.

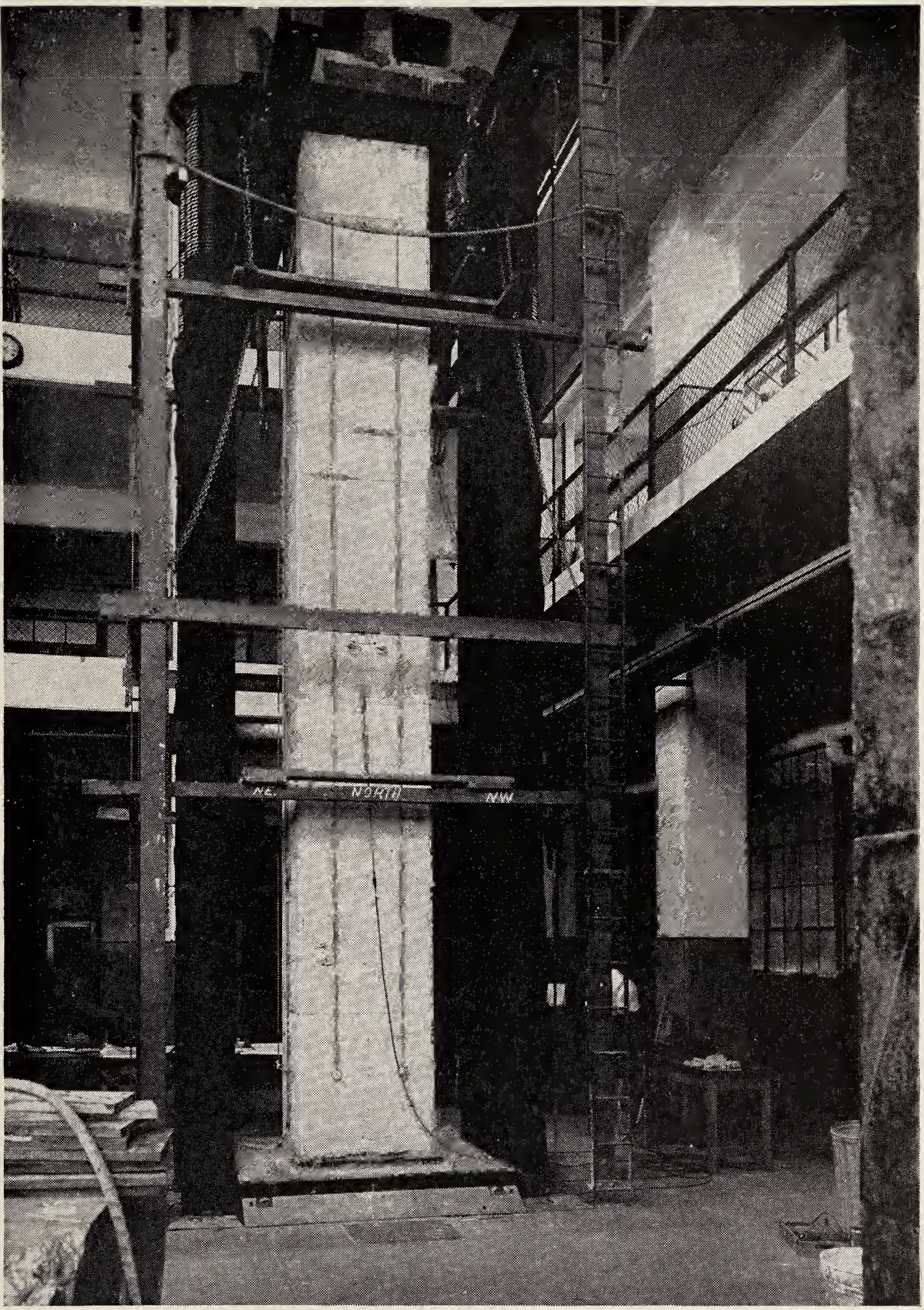
TESTING PAINTS. Three years of Washington weather did this to common brick painted (19, above) with an oil-base masonry paint and (20, below) with one type of rubber-base paint. For a durable coating Bureau chemists found it necessary to even the surface with a coat of grout, then apply a coat of rubber-base paint followed by masonry oil-base paint.

WEATHER SPY. 22. This is "Grasshopper," an air-launched automatic weather station developed by N.B.S. for the Navy's Bureau of Ships. Grasshopper is dropped behind enemy lines by parachute. The landing impact sets off an explosive charge which disengages the parachute. Other charges operate the leg-release device, which sets the station upright (21 opposite), and erect the broadcasting antenna. The station then begins transmitting information on temperature, barometric pressure, and humidity.

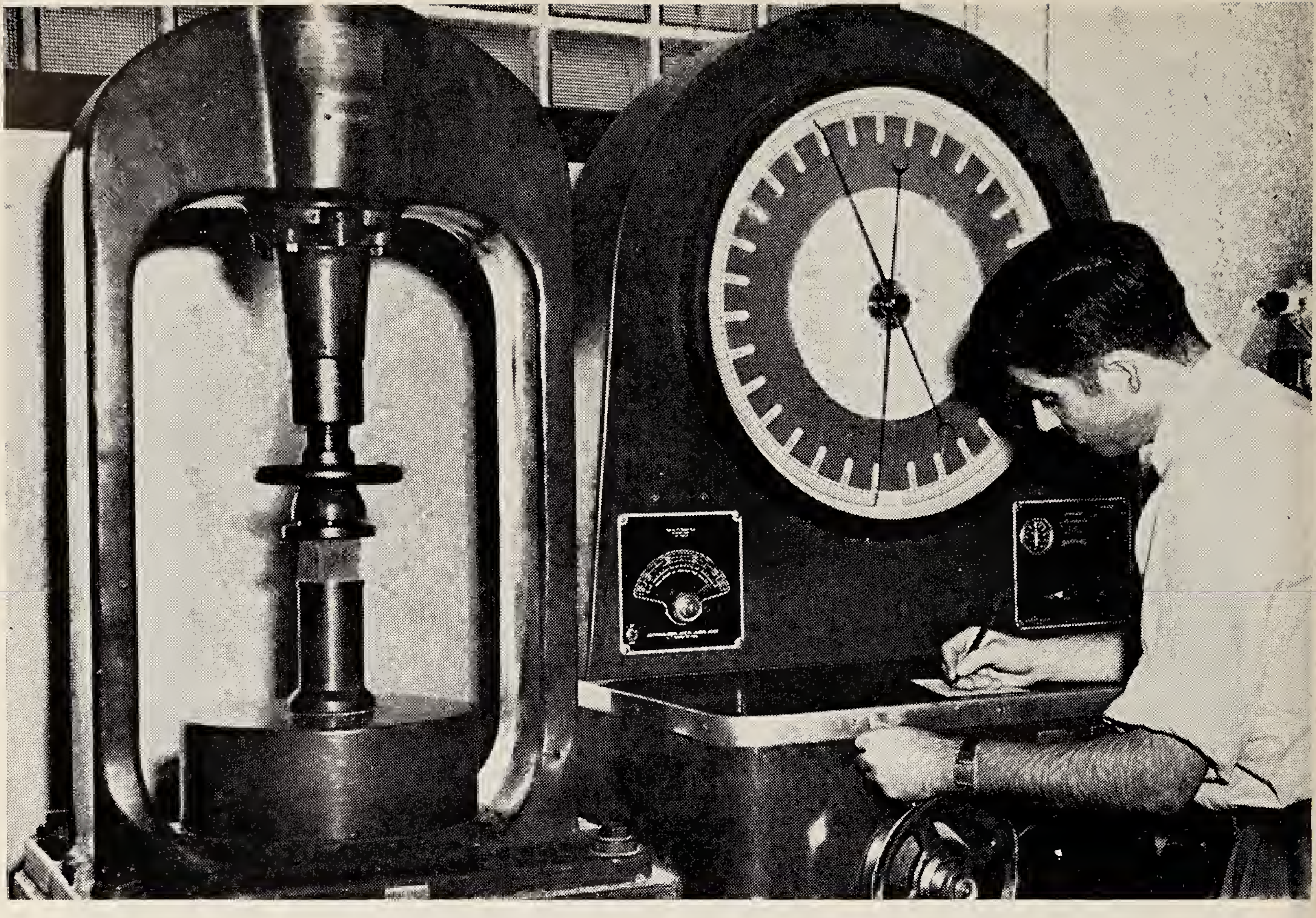




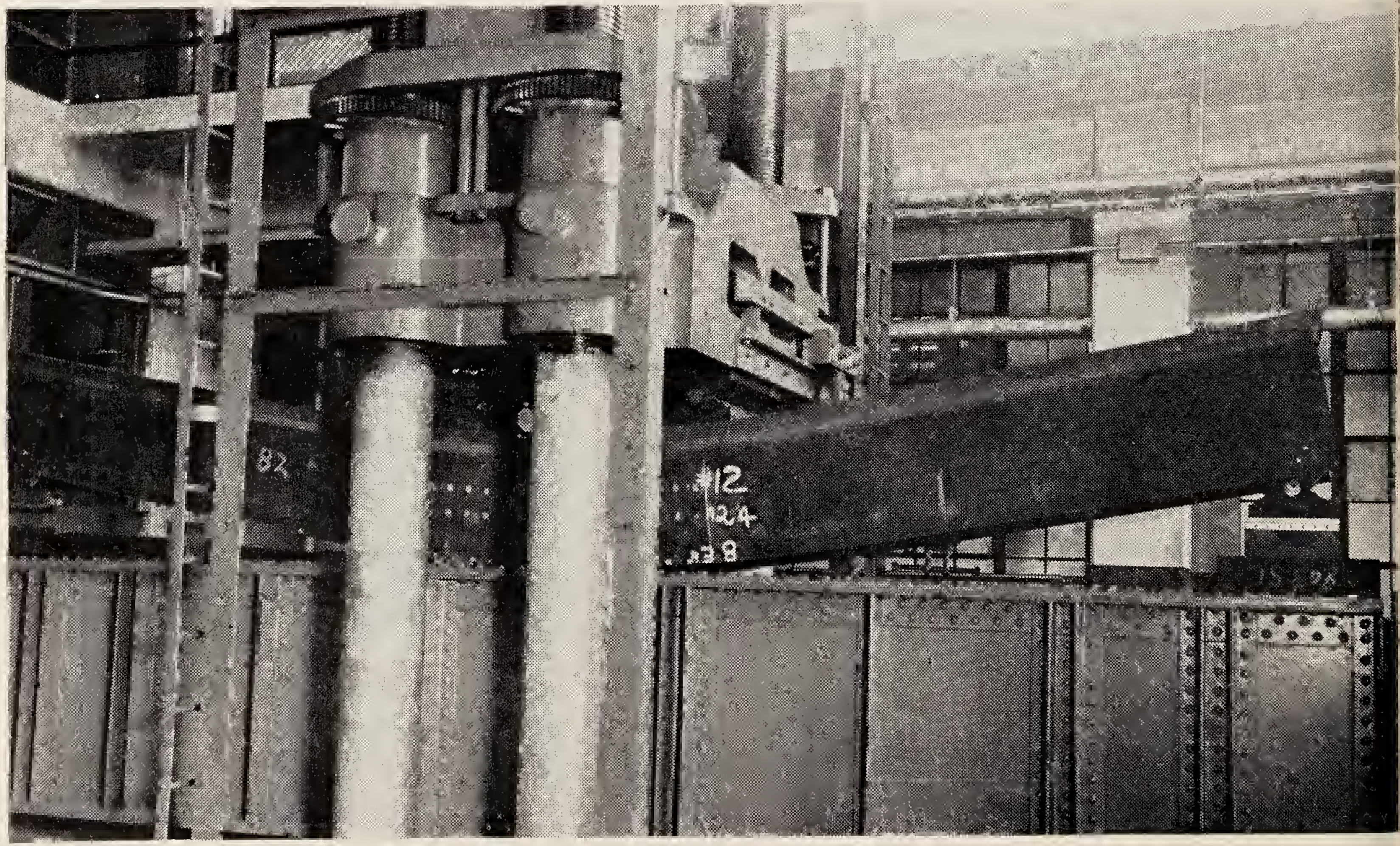
MATERIALS AND STRUCTURES RESEARCH. This 10-million-pound compression machine, probably the world's largest, is used to test full-scale

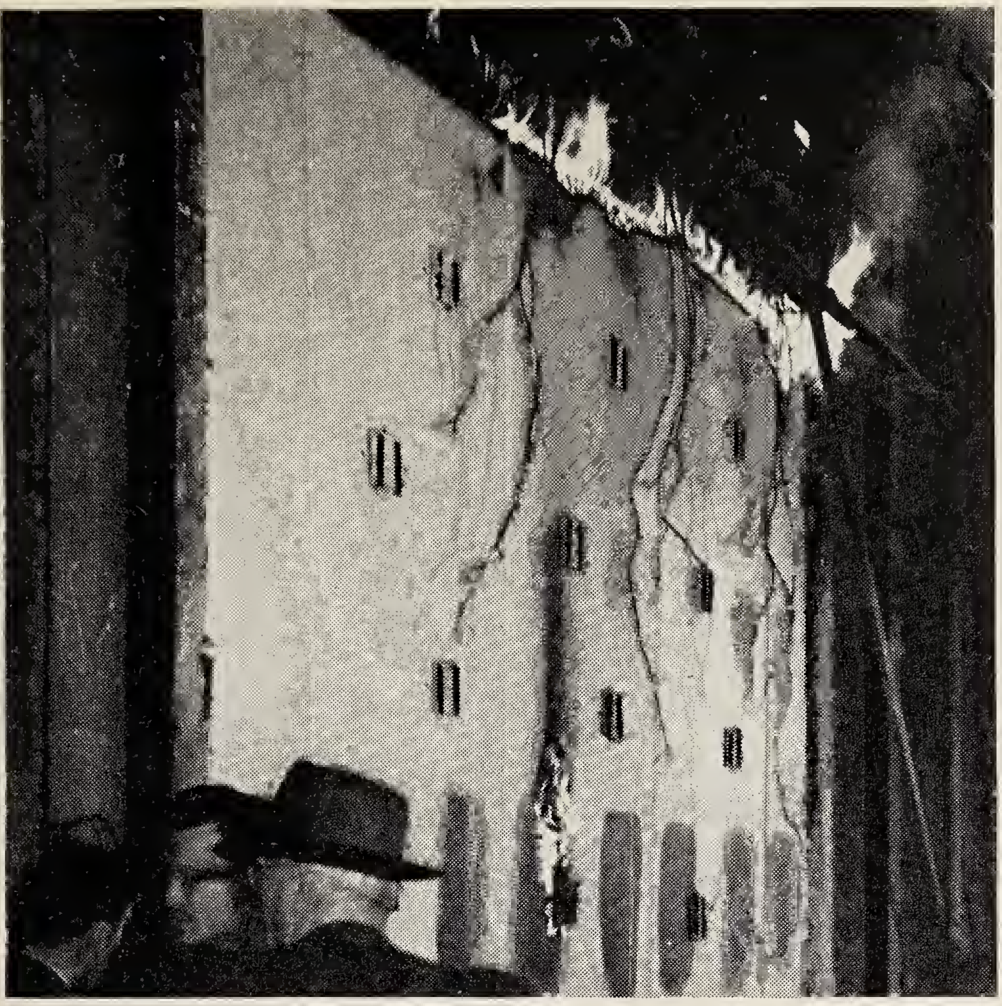


structural units, often the only reliable indication of performance in service. 23. The column at the left has just failed. 24. The one at the right awaits its ordeal by compression.



MATERIALS AND STRUCTURES RESEARCH. 25. Above is a standard testing machine, testing the compressive strength of a cube of Portland cement. 26. This is what happened to a 9-ton 22-foot welded steel girder when a load of 1,685,000 pounds was applied.

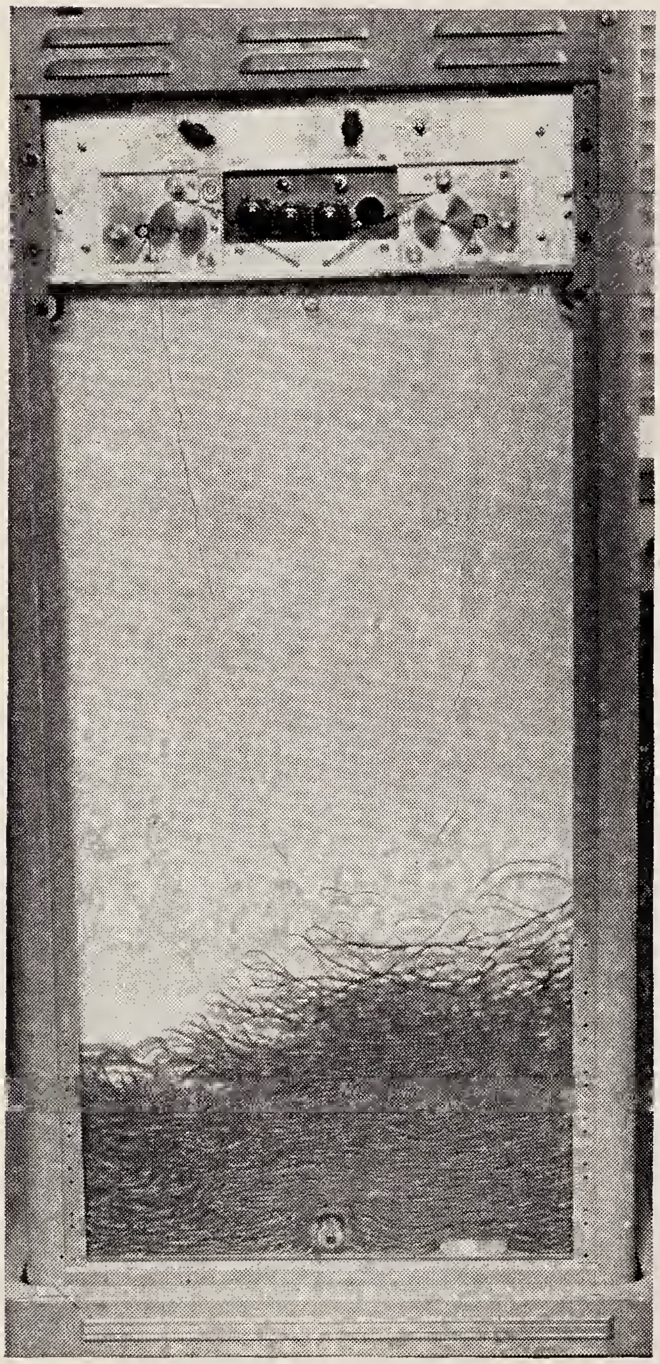




27. This is a fire test of a prefabricated wall structure. On the opposite side of the wall, a regulated fire is burning. Thermocouples mounted on the wall record the rise in temperature. The dark blotches are scorching. When this picture was taken, failure had just occurred, with flame breaking through at the lower center.

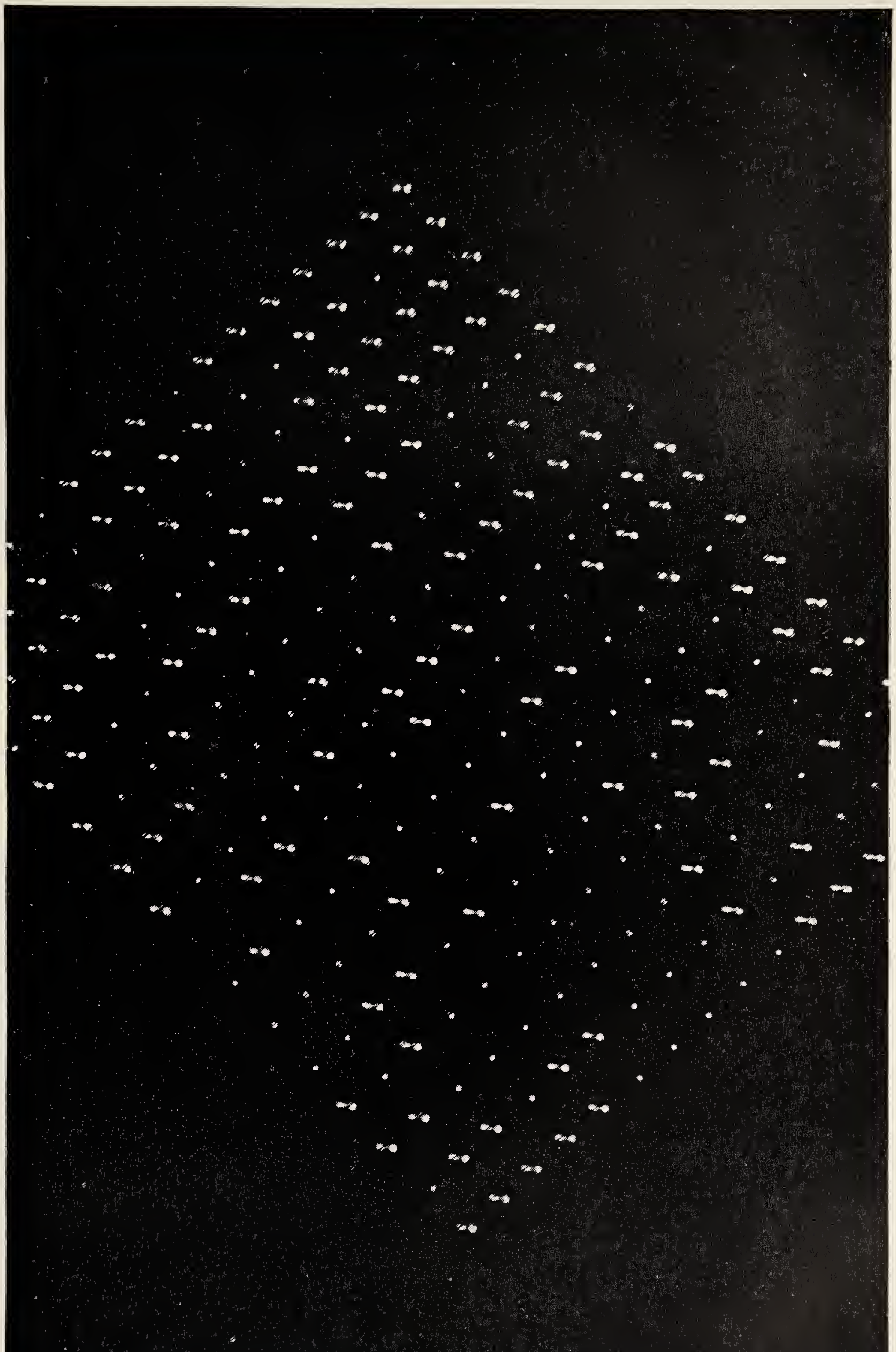
28. In 1928 the Bureau had a rare opportunity to make a full-scale burnout test in the heart of downtown Washington. Two buildings ready for razing were filled with materials equivalent to the contents of ordinary office and warehouse space. With instruments placed at strategic points, the buildings were ignited. The results helped to shape modern building codes.

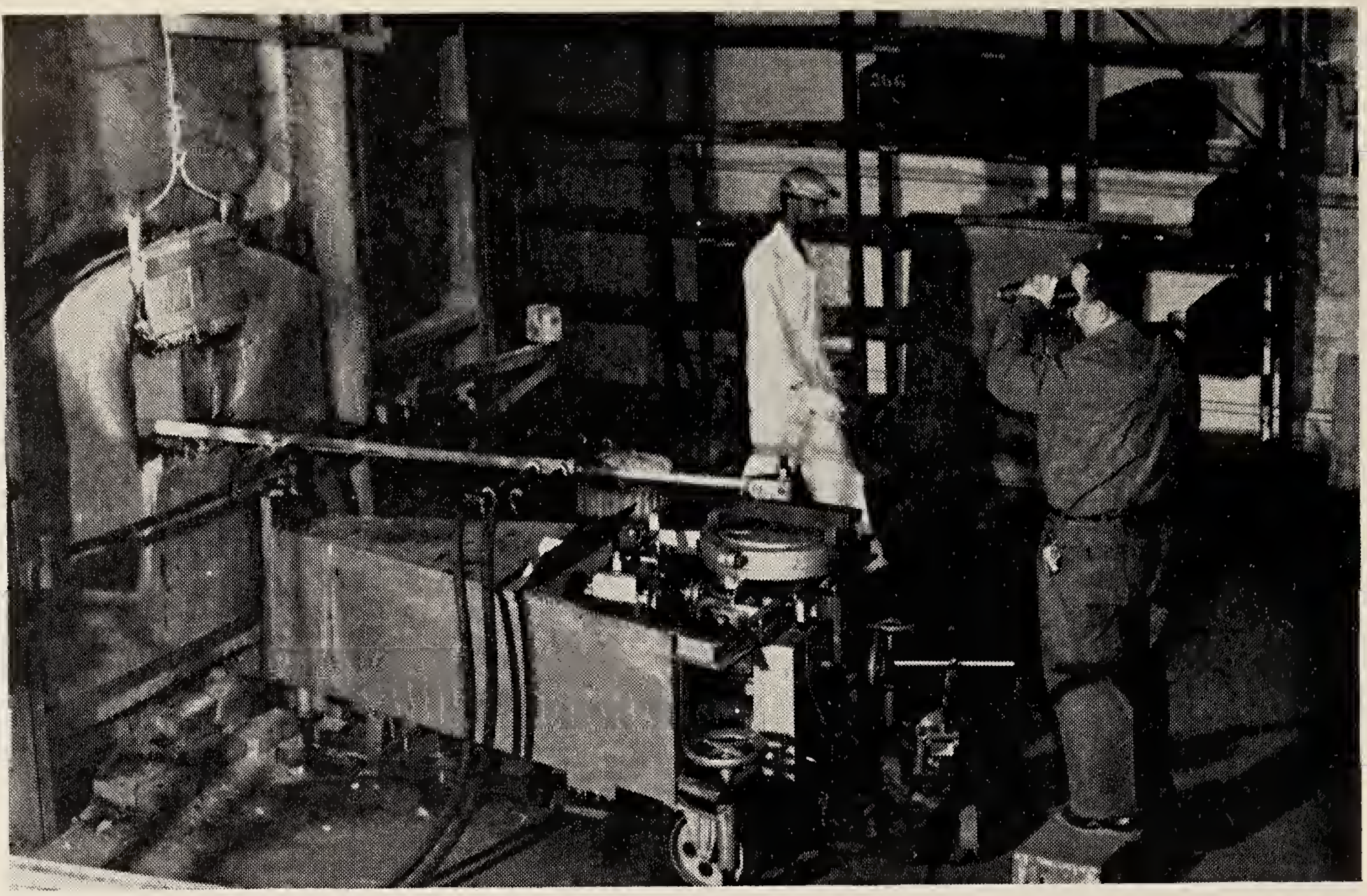
A COMPUTER AND ITS MEMORY. 29. This is SEAC, Standards Eastern Automatic Computer, described in Chapter 15.



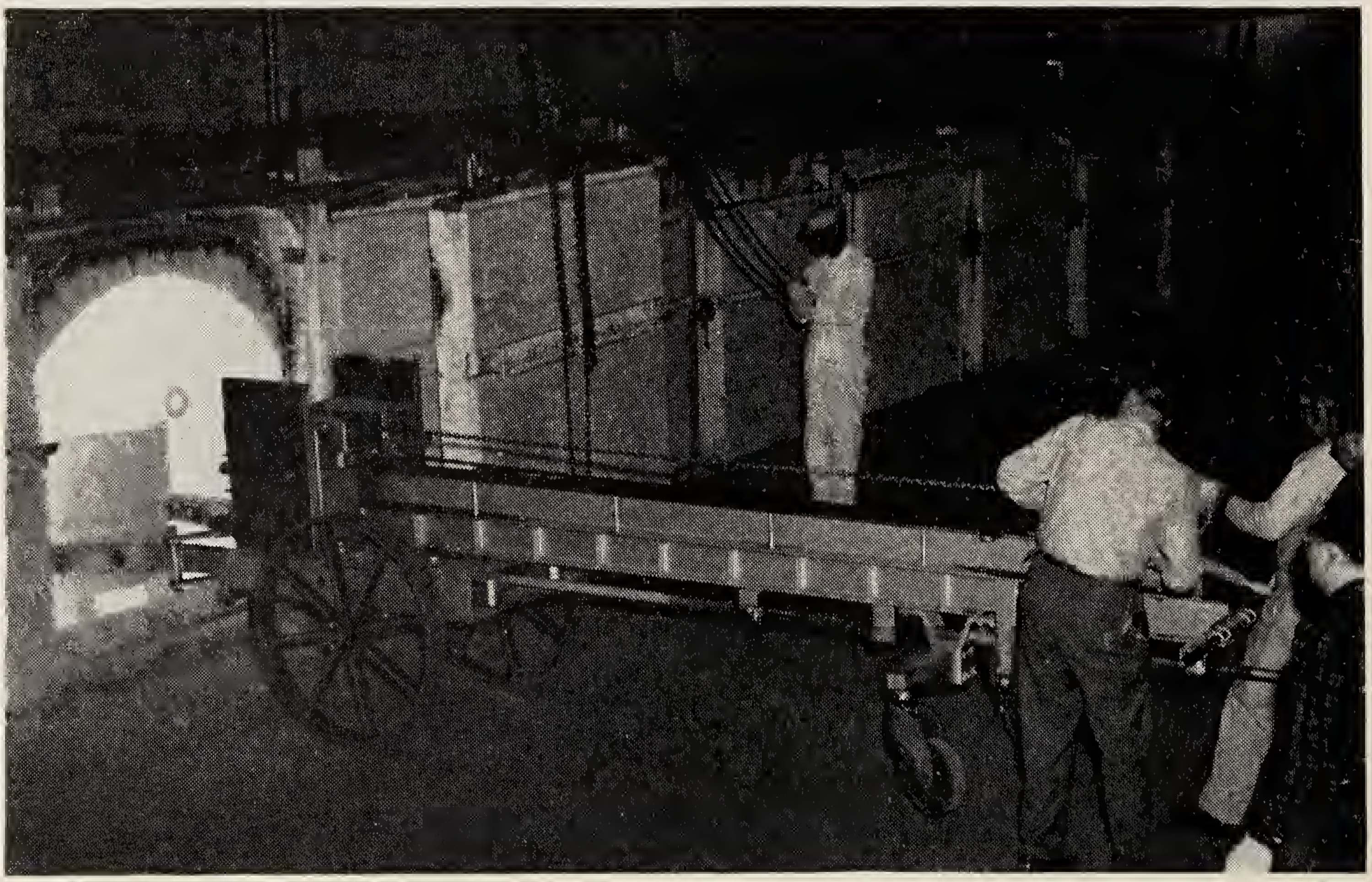
30. SEAC's magnetic-tape memory is slower, but much more capacious. Information in binary code is stored as magnetic pulses on this tape, a loop falling in loose folds in the glass tank. The unit is computer-controlled, starting, stopping and reversing automatically, so that the section of tape holding the needed information is quickly brought through the reading head. Erasing and storing new information are also automatic.

31. Part of SEAC's memory is provided by a number of Williams tubes, which resemble television picture tubes. The photograph opposite shows information in binary code stored on the face of a tube as a pattern of bright spots.

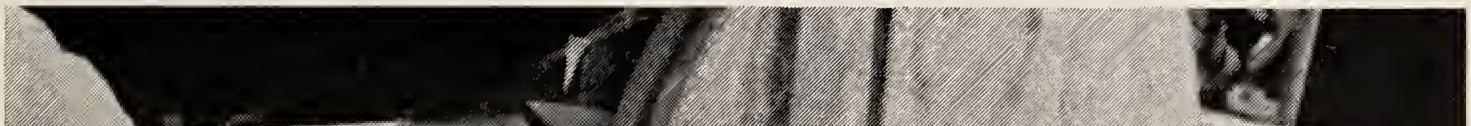


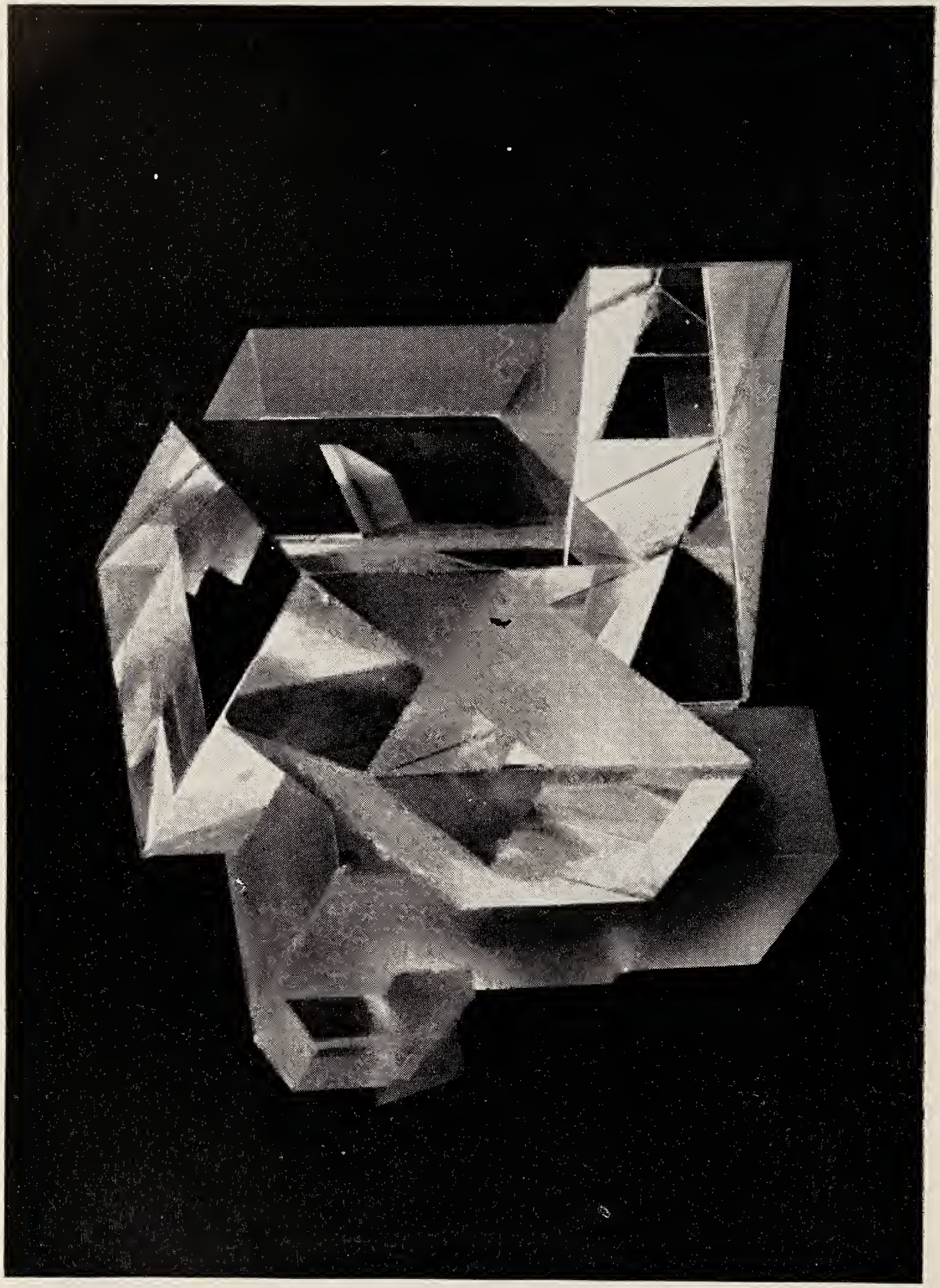


OFFICIAL GLASS FACTORY. In two world wars the Bureau provided supplies of optical glass and technical guidance that helped establish the optical glass industry in the United States. 32. Specially prepared ceramic crucibles hold the ingredients. In the upper view, a crucible is being removed from an electric furnace, where it was preheated. 33. Molten glass is stirred mechanically as it is brought up to the proper temperature, a 24-hour process. Below, a skilled worker is reading its temperature with an optical instrument.

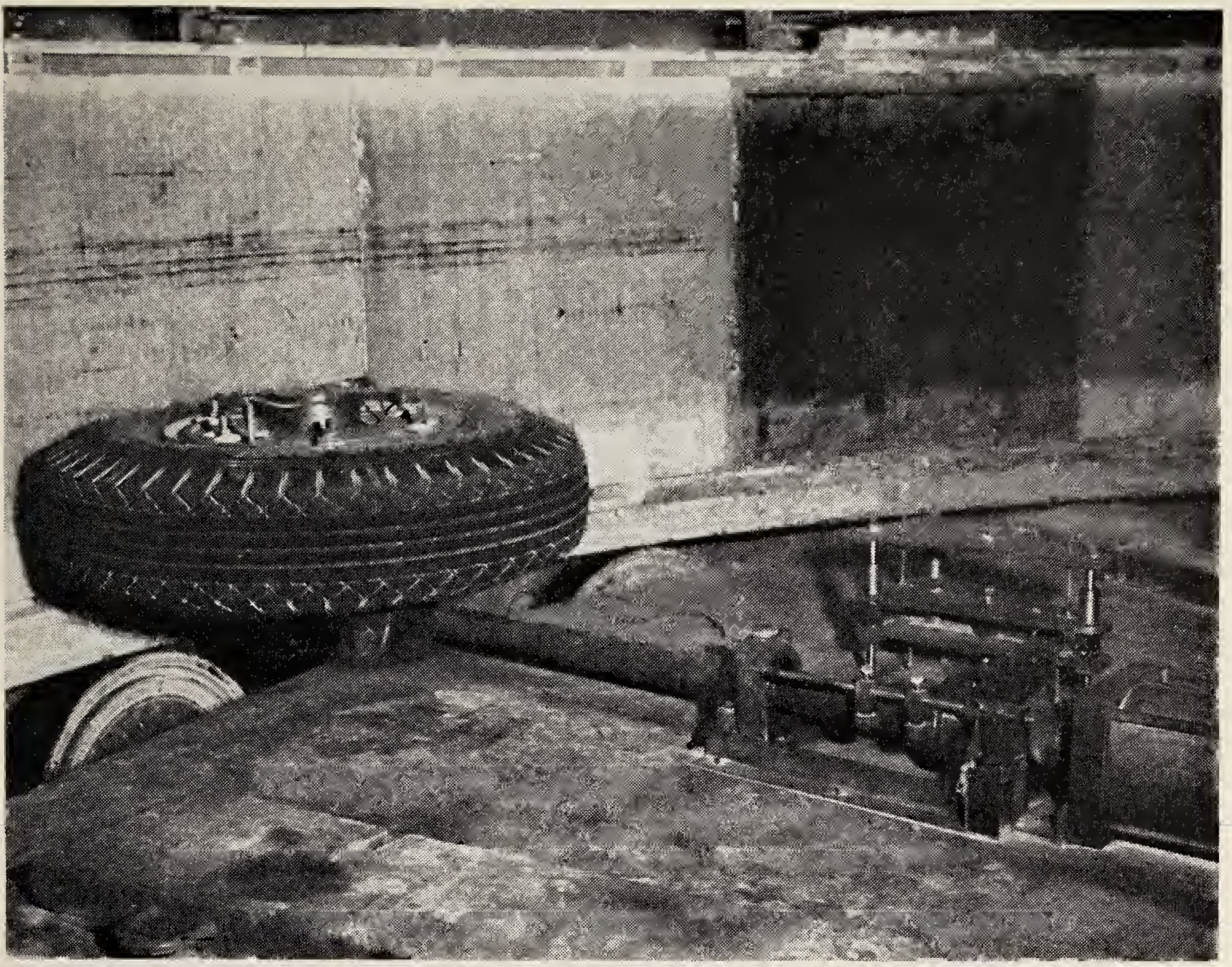


34. After long, slow cooling, the crucible is shattered, and pieces of optical glass are inspected and graded. 35. In the picture below, blanks are cut from the chunks with a diamond saw.

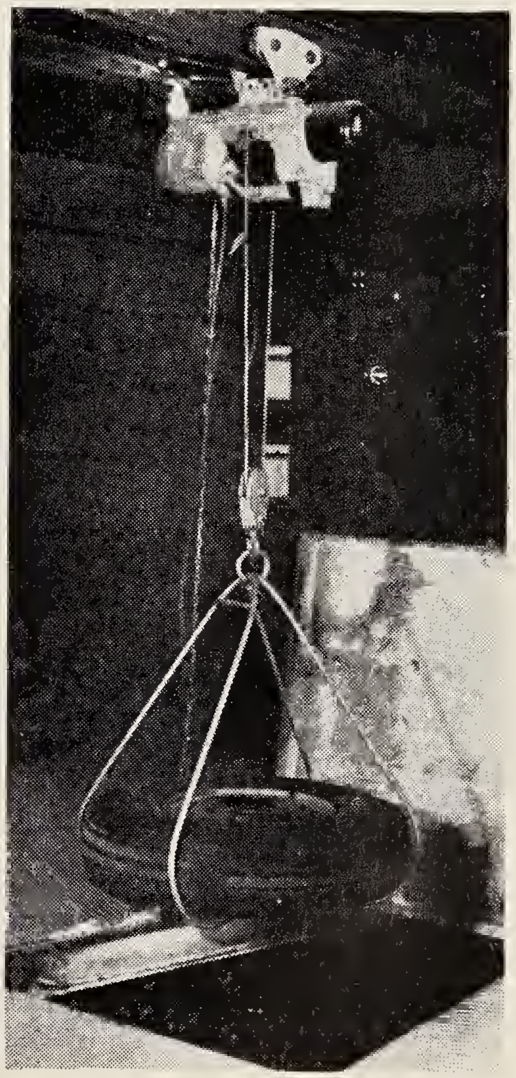


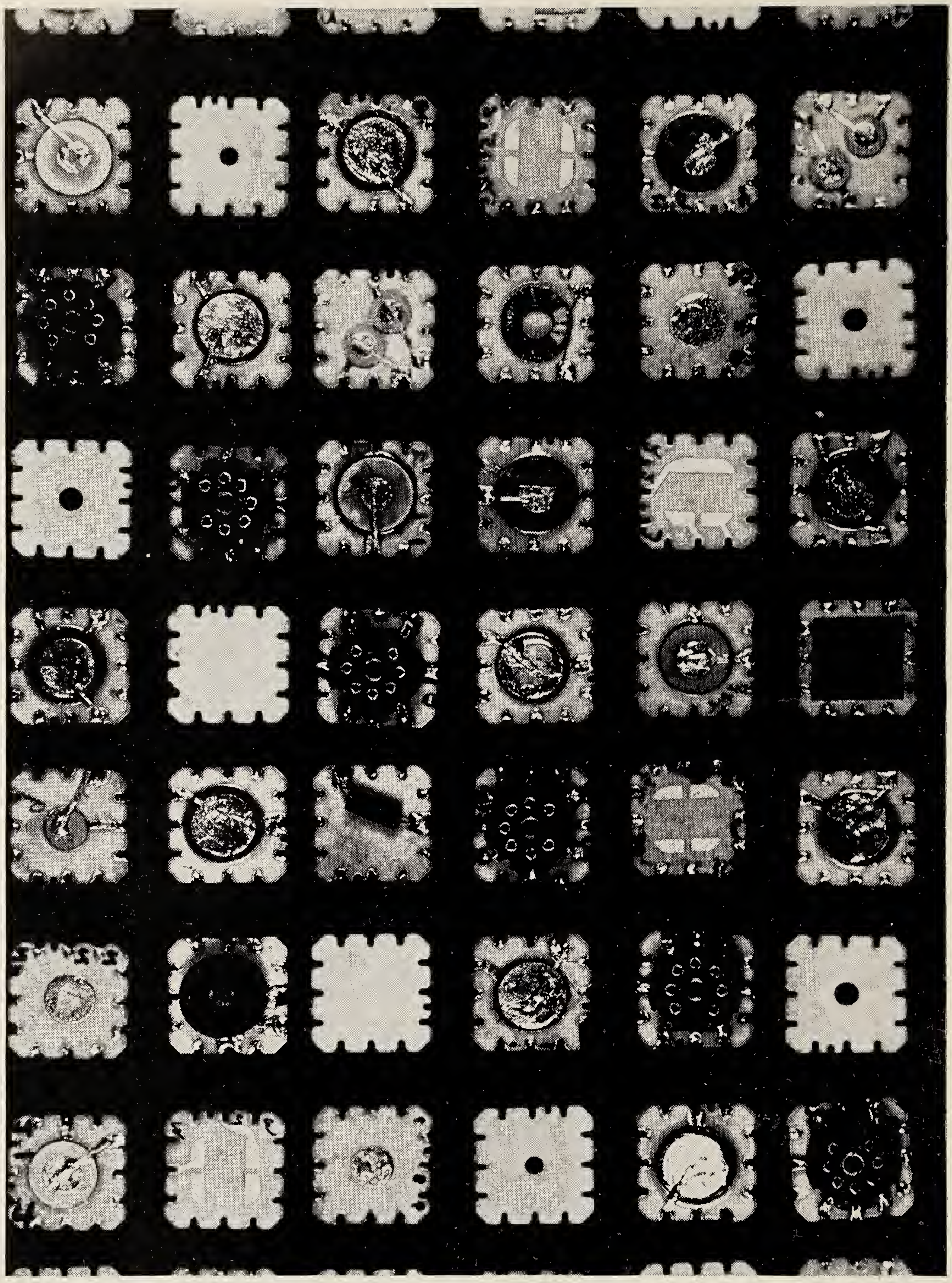


COINCIDENCE PRISM. 36. One of the most intricate and costly of optical devices, it is used in range finders. It was made at the Bureau by cementing together a number of smaller prisms.



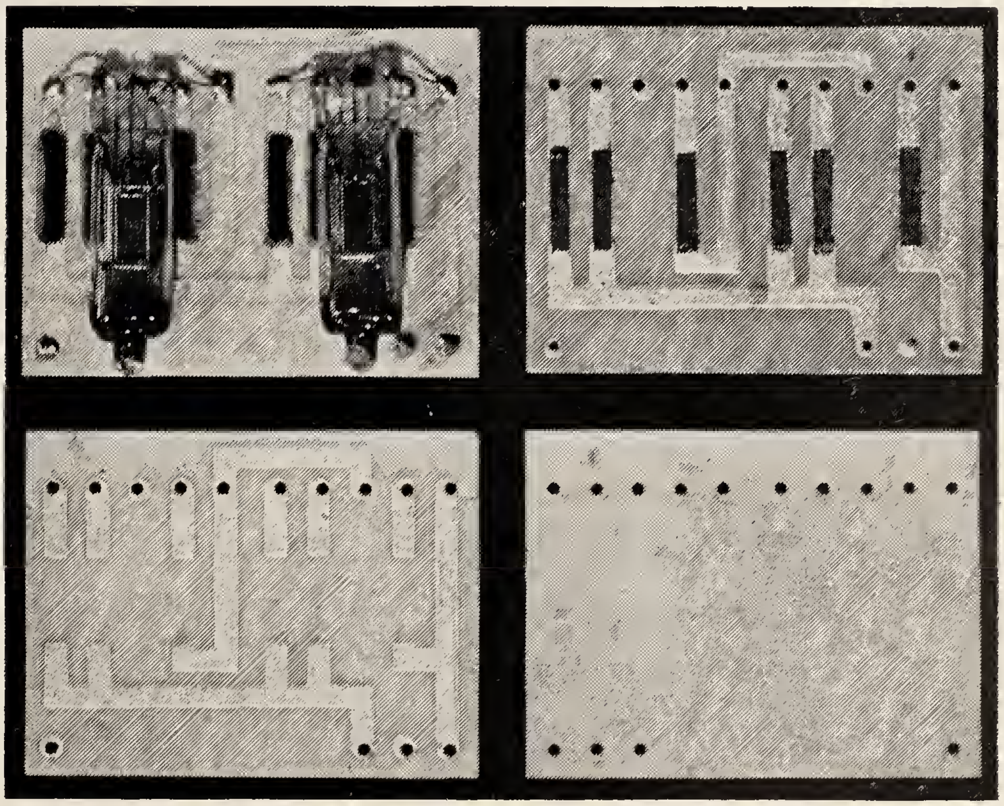
TIRE TESTING. Service tests of manufactured products have two common pitfalls: in field tests it is difficult to control conditions precisely, while laboratory methods may not reproduce actual conditions of use. 37. The Bureau's new tire-testing laboratory duplicates highway conditions. Tires can be tested here more quickly and at lower cost than by the former method—putting them on trucks and driving thousands of miles. The "road" is a revolving drum, faced with concrete or other material in segments. Shown in the picture are several segments of concrete and one of wood blocks. Speeds in excess of 60 miles per hour can be obtained. A blower and aluminum dust reproduce normal highway dusting. 38. Right, a tire being lowered into position.





TINKERTOY. In a pilot plant designed for the Navy's Bureau of Aeronautics, automatic machine methods have been applied to the manufacture of electronic equipment. This one is known as Project Tinkertoy. Machines produce ceramic wafers, process and apply a variety of parts, assemble modules (see frontispiece), and perform inspections. 39. Above, some of the ceramic wafers with circuit components applied.

40. Blank wafers are fed into the machine in the top photograph, which prints up to six circuit patterns simultaneously. 41. The lower view shows four steps in an N.B.S. method of making printed electronic circuits.



42. Comparison of a standard two-stage amplifier and a miniature amplifier with printed electronic circuit and subminiature tubes.

Photographs, Courtesy of National Bureau of Standards, except pictures 27, 32, 33, 34, 35, 37, 38.

For whether he liked it or not, this was the scientist's war. As the President's Scientific Research Board said when it was over: "the laboratory became the first line of defense, and the scientist the indispensable warrior."

Throughout World War I the Bureau had continued its usual publications, including annual reports in which references to military projects were frequent. But in World War II the Bureau vanished behind the wall of security. Van Ness Street, passing through the Bureau grounds, was closed. Guards patrolled the grounds and fences, and visitors' credentials were carefully checked. There were good reasons, not all made public yet, though the Bureau grounds are open again. Behind the fences, terrible new weapons were being fashioned by the indispensable warriors.

It was not all weaponry, to be sure, and some of the work was reminiscent of the earlier war: finding ways to conserve scarce materials, testing substitutes, trimming specifications to the minimums of safety or adequacy, standardizing to reduce the number of varieties and styles. The Bureau had a lesser share of materiel testing than in the earlier war, for the armed forces now had huge testing laboratories of their own; but there was more than enough to keep everyone working overtime. This war was fought in every kind of climate. That meant new problems, for military equipment designed for use in the temperate zone often failed under conditions of extreme cold, heat, or humidity. Electric batteries, particularly sensitive to weather, gave constant trouble until new types were designed and built.

Radio communication was far better than it had been in World War I, but it was still far from perfect. No one had yet learned how to cope with bad "radio weather," those times when signals faded or were drowned out by static. In peacetime bad radio weather might delay a message or interrupt a scheduled broadcast. It was a nuisance then; in war it was sometimes a disaster.

One night, for example, a British bombing squadron flew a mission over Germany. Visibility was poor, but that gave the bombers some protection from Nazi fighters and anti-aircraft. They dropped their bombs and headed back, homing on a radio beacon. Somewhere near the English Channel, radio communication failed; a bad spell of radio weather was beginning. They were lost, cut off from the world below,

wandering through the clouds looking for a way down. Some did, landing at airfields or in open country. Others, as their gas gages approached "Empty," made desperate attempts to land. A few crashed on land; others were never heard from again.

This was a crisis, and a new high-priority assignment for the Bureau. What could be done about these radio blackouts?

There didn't seem to be much hope of "weather-proofing" radio signals. But accumulated evidence offered one lead: not all frequencies were affected in the same way at the same time. In fact, if the radio operators of the lost squadron had only known, they might have switched over to another frequency on which communication was still possible. But how could they know? Could radio weather be *predicted?*

It was a good lead, and after a year of high-pressure work the Bureau had the beginnings of an answer. On March 10, 1942, the first regular bulletins were issued, predictions of radio weather for military radio men.

At first these predictions were based on geomagnetic data gathered from Coast and Geodetic Survey observatories, plus ionospheric data. Later more and more kinds of information were gathered and integrated, data on solar activity, radio communication reports, geomagnetic records, and observations on direction findings.

Radio weather forecasting is a regular Bureau service now, no longer secret. Radio operators around the world receive the Bureau's monthly bulletins and plan their schedules accordingly.

Another Bureau war project began with several air disasters. No one knew what caused them, at first. A single plane, operating in clear weather, would crash, with no sign of enemy action or mechanical failure. Fitting scraps of information together, experts suggested a probable explanation: pilot failure, caused by carbon monoxide poisoning.

It made sense. As every motorist knows, or ought to know, an automobile engine running in a closed garage will generate a deadly concentration of carbon monoxide in a few minutes. "Deadly" is anything more than 4,000 parts of carbon monoxide (CO) per million parts of air, less than half of one percent.

At sea level, one would not expect to find so high a concentration

in the cabin of an aircraft. But what about higher altitudes? There would be no more CO present—but there would be less air! Cabins of combat planes are usually unpressurized. Fifty parts in a million might impair mental alertness sufficiently to cause pilot error. The amount of CO which would do no more than cause a bad headache at sea level could kill a pilot flying at high altitudes.

The best safeguard, investigators agreed, would be a warning device. They laid down the specifications: simple, sure, quick. A Bureau team met them, designing a glass capsule filled with a CO-sensitive compound. Snapping off one end of the capsule permitted air to enter. If CO were present, the compound changed color. A color chart told how much. The device, produced in quantity for about ten cents, detects a few parts of CO per million.

Almost everyone wanted to do his bit, including inventors and would-be inventors. The day after Pearl Harbor they began coming to Washington, writing, telephoning, offering their ideas, sometimes in blueprint or model form, more often only in words. Most ideas were worthless, but one or two percent had merit, enough to compensate for the labor of winnowing. The National Inventors Council was set up to do the sifting job. Their staff men listened politely to the gibberish, wrote polite notes even to those correspondents who gave mental hospitals as return addresses, and tried to keep their minds open to the rare scheme which might sound wild but might also bear the touch of genius. If something came along which stood up under preliminary checks, they passed it along to the Army, Navy, National Bureau of Standards, or wherever else it seemed to belong.

Why not equip a species of giant bats with incendiary bombs and release them over enemy cities at night? Crackpot? Maybe—but the man who suggested it turned out to be one of America's foremost zoologists! Believe it or not, this one was actually tested over an experimental town in the United States, and it worked every bit as well as the zoologist said it would. The bats sought out the darkest corners in attics and other inaccessible places, ideal for starting fires. Military men decided that other incendiary methods were better, however, and this one was never used against the enemy.

Before the war, a treasure-hunting enthusiast in Miami had en-

listed the help of an electrician neighbor in building a device to detect buried pirate gold. The staff of the National Inventors Council heard about it and passed it along. Result: the American Army Mine Detector, which saved countless lives in North Africa. It was portable, carried by one man, able to locate metal particles buried 30 inches deep. The best British and German detectors faded out at six or seven inches.

An Indiana inventor submitted a clever design for a finger-operated spark generator. It was ingenious, but none of the services could think of any use for it. Later the bazooka was invented, and the original battery-operated firing mechanism was unsatisfactory. Someone recalled the trigger generator and the problem was solved.

War in the Pacific cut off supplies of kapok, used to keep lifejackets afloat. A civilian scientist, Dr. Boris Berkman, found that the floss of ordinary milkweed was not only a substitute but was actually better than kapok for some uses. The Council passed the idea to the Navy, and the Navy wrote a contract for a million pounds of milkweed floss to be processed in a Michigan plant. Bands of school children were enlisted to scour the fields and acres of milkweed were planted.

The story can now be told of a secret meeting held in New York in 1942. The Council and the Office of Strategic Services summoned a group of railway engineers, maintenance and operations men, locked them in a guarded room, and posed a question: "What's the best way to wreck a train?" They were shocked; it was like asking a policeman how to rob a bank or a doctor how to spread disease. But they pulled themselves together and provided material for a film and manual used in the training of agents operating behind enemy lines.

One of the Council's finds was a Texan, R. A. Salathiel, who invented a breath heater. The problem he attacked was serious in the Arctic, for in sub-zero weather, no matter how warmly a man dresses, he loses large quantities of body heat simply by breathing: inhaling cold air, warming it in his lungs, and then exhaling the warmed air. Salathiel's device was nothing more than some steel wool packed in a tube. Exhaled air warmed the steel wool. Inhaled air was warmed by the steel wool. Both the Bureau and the Quartermaster Corps tested it and found that it worked. Having made his contribution, Salathiel

refused to have anything more to do with it. He wanted no money, no credit, and wouldn't apply for a patent!

The Bureau's optical glass factory stepped up its operations, and it became a training school for technicians to operate new plants built by industry. Bureau men flew to battlefronts on testing and trouble-shooting missions.

But all of these projects were overshadowed by three tremendous undertakings of World War II: the guided missile, the proximity fuze, and the atom bomb. Credit for pioneering in nuclear fission is widely shared by many individuals and groups. The basic work was done in Europe, not America; interest did not begin here until January 1939 when Otto Hahn and F. Strassman, in Germany, published the news that they had achieved an experimental splitting of the uranium atom. Of the scientists who sought to interest President Roosevelt in the possibility of developing nuclear weapons, most were Europeans.

Two years before Pearl Harbor, Roosevelt was approached, and he appointed Bureau director Lyman J. Briggs as chairman of a special secret committee to investigate the matter. From that point on, the Bureau was deeply involved in the many lines of research and development which culminated in the first atomic explosion. The liquid thermal diffusion process, for example, was proposed by P. H. Abelson of the Carnegie Institution; he demonstrated it in his laboratory at the Bureau, and saw it realized in the huge Clinton plant at Oak Ridge, Tennessee. A Bureau scientist, Dr. J. I. Hoffman, found a simple chemical method of purifying uranium. The Bureau was control laboratory for uranium and other products. Materials were tested, standards were established, instruments were designed, safety measures were prescribed. Extensive research in isotopes was conducted behind the fence along Connecticut Avenue, and a number of Bureau men vanished, not to be heard from again until the existence of Oak Ridge and Los Alamos was made known.

The second project was the proximity fuze, initiated in December 1940. It is easy enough to say what such a fuze does: it explodes a shell or rocket or bomb at its nearest approach to the chosen target. Building such a fuze was another matter. The problem was to design a self-powered radio transmitter, a receiver, a device to analyze the reflected signal, and a detonating mechanism; to build them so small

that the entire apparatus could be crammed into a space about the size of a baseball; and to make them rugged enough to withstand immense shocks and stresses. Of course, the fuze must not mistake the launching ship or plane for its target!

Even if such a thing could be designed, the parts to make it didn't exist. Before the first fuze was built, dozens of research teams at the Bureau and in other laboratories had to develop radically new ideas in electronics, miniature vacuum tubes, tiny power sources and other components.

The guided missile, called The Bat, was even more complex, though space requirements were less exacting. The Bat is launched in mid-air. Its target is first located by the standard search radar of the mother plane. The mother plane then heads for the target, while The Bat's radar is adjusted to the plane's radar. The operator then switches to automatic tracking and the missile is released.

The Bat is then on its own. Locked to the target signal, its radar signals are analyzed by a computing mechanism which controls the steering apparatus. Day or night, in any weather, The Bat pursues its target, changing course if the target changes course. In the last year of the war, The Bat destroyed many tons of Japanese shipping.

When the war ended, the Bureau's staff had more than doubled. Its own budget was larger, and war projects, financed chiefly by other departments, were putting an added $10 million into its operating funds.

What now? Would the "indispensable warrior" return to peacetime pursuits? In a changed world, what was to be the future shape of scientific research?

13

THE CRISIS IN SCIENCE

Things would never be the same again. When the war ended, the United States needed a new national science policy, and the scientist needed a new concept of himself. Incredible changes had taken place, but anyone could see this was only the beginning.

Some of his fellow-citizens had looked on the scientist with respect, as a truth-seeker, discoverer, creator. Others had regarded him with tolerant amusement. He was bright but impractical; it took an engineer to turn his work into something useful.

Now, with the echoes of Hiroshima and Nagasaki reverberating around the world, the scientist had suddenly become an awesome creature who held the fate of all humanity in his hands. In war, his weapons could destroy civilization. In peace, the forces he commanded might change the shape of the earth, make giant industries obsolete, conquer disease, prolong life, eliminate the need for man's muscle and brain in much of the world's work.

The scientist himself felt uneasy and awkward in his new role. Aware of the powers he had unleashed, he was frightened by them, and unwilling to have them wielded by soldiers and politicians who, in his judgment, neither understood them nor had the kind of philosophy which would assure their wise use. Individually or in such groups as the Federation of Atomic Scientists, many of those who had had little interest in politics before now sought to influence national and world affairs. The scientist was thrown into situations of conflict,

with the military, with secrecy and security machinery, and with groups fighting for control over nuclear power.

How much research would be done in peacetime, and by whom? In 1932 the entire federal government had spent only $40 million for research. In the last year of the war the budget had reached a staggering $1,600 million, forty times as much. But by the time President Truman appointed his Scientific Research Board in 1947, annual research appropriations had been slashed by more than one-third. More than $600 million in projects had been lopped off.

This was partially offset by expansion in industry's research, but the President's Board expressed grave concern. Research expansion must continue or the nation's security will be endangered, they warned. Expansion would be slowed by scarcity of scientific manpower. But the Board projected a goal for 1957 which, at the time, seemed bold and probably unattainable.

Two historic facts swept all plans and predictions aside; news of Soviet atomic weapons and the Korean War. The Board's 1957 goal was surpassed in 1949. By 1953 federal expenditures for scientific work had topped $2 billions. So far this is a peak, or, rather, a plateau, for the level is being maintained. But instead of dropping off, as it did in World War II, industrial research is still increasing. It means bigger and better laboratories, competition for scientific manpower, bigger and better jobs for scientists. In general, these are lush times for the scientific community.

But a warning issued by the President's Board in 1947 is still valid. Just spending a lot of money doesn't assure good results. Indeed, some thoughtful scientists say that the present pattern of government-sponsored research endangers America's future. For while expenditures are at an all-time high, some branches of science are starved for funds.

Scientific research is divided roughly into two main categories: *basic* and *applied*. Basic research inquires into the fundamental principles of nature. Applied research turns the fruits of basic research into machines, weapons, devices, instruments, methods, and so on. Basic research is sometimes called "pure" or "theoretical." No little mischief has been wrought by caricaturing the "pure" scientist as an aimless explorer who devotes years to the study of trifles, without interest in whether the results he obtains will be of any use. There seems to be

an implication that he will be happier if they aren't. By contrast, according to this distortion, the applied scientist knows what he wants and goes after it.

Those who accept this caricature fail to understand—and their failure may prove disastrous—that basic research and applied research are not different activities, or alternatives, but steps in a sequence of events, and basic research necessarily comes first. Until basic research has been successful, there is nothing for applied research to apply.

It is true that the immediate objectives of a basic research project may promise no glowing prospects of new products or new industries. The first men to think about the nature of matter were philosophers, and who can be less practical than a philosopher? Of what possible use did it seem, in earlier times, to know that there were such things as atoms, electrons, protons, and neutrons? Even in the 1930's radio comedians could always get a laugh by mentioning Einstein.

It takes time. Einstein's mass-energy formula $E = mc^2$, appeared in a paper he published in 1905. Man's first large-scale conversion of atomic mass to energy was the explosion at Alamagordo, New Mexico, in 1945.

But to say that a basic research worker has no objectives in terms of new industries or products does not mean that he has no objectives at all. On the contrary, his objective may be as specific as a project in applied science. Joseph Henry sought understanding of the relationship between magnetism and electricity. What he discovered led quickly to numerous applications: the telegraph, the electric motor, generator, and transformer.

The caricature of the pure scientist evokes an opposite caricature of the applied scientist: he is a crass individual, an engineer-mechanic, who sells his soul to the highest bidder, usually a large corporation. There is just enough truth in both distortions to cause trouble. Among scientists themselves one can find attitudes suggesting that basic research is more virtuous. Those in basic research sometimes resent the fact that most of the money goes into applied research, that men engaged in applied research are paid higher salaries and have better-equipped laboratories; while among applied scientists there are occasional guilt feelings.

It would be helpful, in working out a national science policy, if

such attitudes could be put aside; for it is self-evident that basic and applied research are both essential to scientific progress. What's wrong with our present national policy is not that too much money is being spent on applied research, but that too little is being invested in basic research.

Basic research does not progress at a smooth and even rate, but by "break-throughs" at the very frontiers of human knowledge. Each significant break-through opens the road to many new developments in applied science. After a break-through there may be a succession of spectacular achievements. In applied research, results are somewhat in proportion to effort. A problem in basic research does not respond in so predictable a manner. A mass attack by a battalion of scientists in a huge and well-financed laboratory *might* gain no more ground than the efforts of a single man.

But while the relationship between effort and achievement in basic research is not as direct as in applied, it is not absent. To a greater extent than in applied research, the triumphs of basic research are scored by men of exceptional ability, men of genius. If such men are not attracted to careers in basic research, basic research will lag. Some authorities say that the extermination of twenty outstanding men would halt American progress in physics for a generation. The same effect would be felt if these twenty were diverted to other careers or denied the facilities and the freedom to do basic research.

The problem of fostering basic research is especially difficult in the United States because of its novelty. We have always excelled in applied research; but we have been dependent on others for basic research. As the President's Board said: "We can no longer rely, as we once did, upon the basic discoveries of Europe. At the same time, our stockpile of unexploited fundamental knowledge is virtually exhausted in crucial areas."

The Board's first sentence referred primarily to the effects of war on European science. There was hardly a first-rate scientist left in Germany, for example. Many had fled as refugees from Naziism. Britain, the United States and Russia sent missions into German territory on the heels of advancing troops, to kidnap, more or less politely, German nuclear physicists, rocket experts, and other scientists.

The sentence is even more true today than it was in 1947, for in

building a security system to keep scientific knowledge from getting out of the United States, we have also prevented much from flowing in. The free international exchange of scientific information is a thing of the past. We dare not share some knowledge with our friends, lest it also reach our enemies.

Face-to-face discussion among scientists has been made increasingly difficult. Many prominent American scientists have been forbidden to travel abroad because passports were denied them or were not issued until they had cancelled their trips. For a foreign scientist to come here as a visitor, lecturer, or delegate to a scientific meeting, is even more difficult. Many resent the intricate procedures and endless interrogations. Indeed, so many foreign scientists have been excluded that a number of international scientific organizations will no longer hold meetings in the United States.

When we exclude a man, we exclude his knowledge. If we have spies abroad, they can doubtless send back technical information, such as the plans for a new rifle or aircraft. But there isn't much even the best-trained intelligence agent can piece together in the lofty regions of theoretical research. Hitler's powerful secret police apparently saw no danger in permitting publication of the Hahn-Strassman papers. Only a handful of men understood their implications. One of them brought the news to colleagues in the United States.

Now we have closed the route by which that man traveled. Indeed, if our present immigration laws and visa policies had been in effect before World War II, we would probably not have had the atom bomb, and Germany might have had it. The basic research came from Europe; many of the key men who led the efforts of the Manhattan District were immigrants or refugees.

When the war ended, most non-scientists were unrestrained in their optimism. We were going to have nuclear power, wonder drugs, a radio on every wrist and a helicopter in every garage. The pathway to the future was wide and free, with new wonders promised at every turn. No one paid much attention to the gloomy warning of the President's Board, that the stockpile of fundamental knowledge was virtually exhausted.

But that was the fact of the matter. The startling achievements of World War II were in applied science. The huge investment in re-

search shortened the time period between basic discoveries and their application, but it did little to stimulate and support new basic research.

The Board noted that in 1947 less than ten percent of the federal research budget was allotted to basic research; much too little, they said. But even this percentage has since declined. In 1953-55 it was about seven percent. Applied research projects, offering the best jobs, were attracting the best men. Government contracts for applied research were monopolizing the facilities of many university laboratories. It was hard for a university to turn down an offer which meant new equipment, bigger staffs, prestige, and better opportunities for graduating students. Basic research was shoved to one side. The frontiers of science were stripped of manpower, and the chances of big new break-throughs dimmed.

In the past, the National Bureau of Standards had been a major center of basic research. In 1932 its share of the Federal research budget was about one-tenth. In 1955 it had more dollars, $6.3 million as against $2.8 million in 1932, but the increase was just about enough to offset higher prices. Its share of the total federal science budget had dwindled, proportionately, to less than half of one percent.

To be sure, projects, mostly in applied research, financed by other agencies added another $13.6 million to Bureau funds. The effect of this was to strike a new balance.

At first, after World War II, the outlook for basic research had been bright, as Director Edward U. Condon said soon after VJ Day:

> "The close of the war found the Bureau almost completely engaged in war research and development. Some war projects were discontinued or curtailed; many were continued, particularly those that showed promise for peacetime applications. Fundamental research in the fields of physics, chemistry, and engineering was resumed, and the tempo of this research has increased as rapidly as reconversion from wartime to peacetime activities permitted. . . ."

But Condon was too optimistic, as he confessed a few years later, after his resignation:

"When I came to Government service at the close of World War II, I hoped and believed that there was to be an era of peace in which fundamental research in science would flourish and be supported by society as a whole as a worthy intellectual activity and for the constructive benefits to man's well-being which it can bring. . . . At this time it seemed that Congress and the people of the United States, impressed by the contribution which applied science had made during the war, were prepared to support a National Science Foundation in a really adequate way—by this I mean to the extent of several hundred million dollars a year. . . ."

Korea and worsening relations with the Soviet Union helped to dash his hopes. Expenditures for military research rose to three times their World War II peak. The Bureau continued its work on weapons. Neglect of basic research was prolonged.

The National Science Foundation, which Condon mentioned, was set up by Congress, after much controversy, to foster basic research by making grants. But Congress placed a ceiling of $15 millions on the Foundation's annual appropriation, and subsequent Congresses refused to appropriate even that much. At the end of 1951, the President reduced by five million dollars his recommendations for basic research in the military departments, adding that amount to the budget of the National Science Foundation. Congress accepted the cut in the military funds but refused to give any part of the five million to the Foundation.

Scientists at the National Bureau of Standards were learning that careers in basic science can be precarious when government is paying the bill. In 1950, 1,330 man-years of times were given to basic research at the Bureau. Congress slashed this by a fourth in 1952, and lopped off another fifth in 1954.

It's true that some basic research is difficult to explain to laymen, and results may seem remote. But not always. Condon's successor, Allen V. Astin, appeared before a House Appropriations Subcommittee in 1954 and explained one need in three sentences:

"At the present time we certify master gage blocks to a pre-

> cision of about a part in 100,000. Some industries now want us to certify these to a part in a million. We cannot do this."

It was just that simple and definite.

Machinists once worked in a tolerance of 1/64th inch. Were that the best they could do today, automobile engines would be much less efficient, and jet engines couldn't be built. Higher speeds, higher loads, greater stresses require greater precision.

Today it is not uncommon for parts to be produced within a tolerance of one ten thousandth of an inch. To do this, production workers and inspectors must have measuring instruments of high precision, carefully calibrated.

Industry standards are maintained by sending master gage blocks to the National Bureau of Standards for certification. Master gage blocks must be accurate to one part in 100,000 if the work produced in the factory is to be accurate to one part in 10,000. Today engineering designs call for greater precision. Some precision industries are technically ready to produce work within narrower tolerances, perhaps one part in 100,000. So, as Astin reported, they want their master gage blocks certified to one part in 1,000,000. They can't improve their production until that's done.

The House Appropriations Committee heard the request and rejected it, refusing a few thousand dollars for basic research which would make such certification possible. Here is one small example, not a very exciting one, perhaps, of a situation where applied research and engineering can make no further progress; the capital provided by basic research has been exhausted.

Why the cuts? Why were funds denied for basic research? Perhaps there is a clue, of sorts, in the opening remarks of the committee chairman, addressed to Dr. Astin as he took the stand:

> "Let us consider the National Bureau of Standards first. As you may not know, we have had some very peculiar and unsatisfactory conditions in the Bureau of Standards back over the last three or four years. For instance, we had an investigation which determined that for a period of years they had lost track, in a part of the Bureau, of when the windows had been washed. . . ."

With this "for instance," the Chairman passed on to other business, leaving all to wonder whether this was a fair sample, or perhaps even the sum total, of the results of this particular congressional investigation.

In 1953, prior to these hearings, the Secretary of Commerce, Sinclair Weeks, had appointed a committee to appraise the Bureau's work. Its chairman was M. L. Kelly, president of the Bell Telephone Laboratories. In one section of his report, which discusses the division of optics and metrology, one can hear echoes of Mr. Baily describing Queen Elizabeth's yard bar:

> "This Division . . . has never had the funds to initiate a program of development of modern length comparison instruments and techniques. With obsolete equipment, the demands on the staff making length measurements and comparisons are so time-consuming as to leave little time, or energy, or manpower for development of new measuring techniques. It is disturbing, indeed, to see that the nation's number one center for maintaining standards of measurement of length is inadequately housed, inadequately staffed, inadequately instrumented, and without adequate facilities for developing improved measuring and comparison instruments and techniques. . . .
>
> "The senior men in this Division are widely known throughout the country for their work in their respective fields. However, there is a dearth of young men in the Division and, though there are a few conspicuous exceptions, the Division will suffer grievously for scientific leadership a few years hence unless competent junior staff members are soon found. They cannot, however, be attracted under present budgetary, space, and program limitations . . ."

The Kelly Committee made a drastic recommendation: that the proximity fuze and guided missile work of the Bureau be transferred to the Department of Defense—men, laboratories and equipment. The Secretary of Commerce promptly agreed, and four of the Bureau's largest divisions, more than a thousand people, were lopped from the Bureau's organization. Rumors of this change had been current for days before the announcement was made. Coming on the heels of the

AD-X2 affair (about which more shortly) the rumor persuaded some people that the Secretary of Commerce was intent on dismembering and wrecking the Bureau. But when the smoke cleared away, there were not many who would take issue with the recommendation:

> "The presence of these programs in the Bureau is impairing its effectiveness for its primary functions. . . . The large size, coupled with the secret nature, of some of the programs has necessitated a large administrative organization within the Bureau whose character has been dictated primarily by the requirements of the military work. . . . The large amount of highly classified work has brought about secrecy, limited freedom of movement, and other restrictions, and has created an environment that is not best suited to the basic programs. . . . The rapid expansion of the military programs had made opportunity for advancement in the Civil Service grades at a more rapid rate in the military area than in the basic program area. . . ."

Even with such sound reasoning behind it, the action was far from painless, especially for the men transferred. Though they might continue to do the same work in the same rooms as before, they were no longer Bureau members, and that meant something to those who had chosen the Bureau as a career. Some objected to working under military administration. A few resigned. In the Bureau the atmosphere soon cleared. Though the AD-X2 matter will not soon be forgotten, suspicions that the Bureau was about to be wrecked were soon dispelled. Astin's reinstatement, it turned out, had been adroitly recommended by Kelly and his associates. And when the appropriations hearings began, the Secretary of Commerce and his staff supported the Bureau's requests as strongly as anyone could ask.

But the Appropriations Committee was unresponsive, even when Kelly appeared, testifying for himself and his fellow-members, all leaders in science and industry from outside the federal service:

> ". . . Our highly industrialized society requires a Bureau of Standards that is the finest that can be created. To the extent that the Bureau is weak or inadequate, our technologic society is handicapping itself. . . . It is not sufficient to have fairly good

> standards of measurement; fairly good methods of testing materials, mechanisms, or structures; or reasonably good determination of important physical constants. The standards, the measurements, the test procedures must be the very best, the most accurate, the most reliable, that can possibly be achieved at any given time. . . ."

The Congressmen listened politely—and slashed another $2 million from the Bureau's $8 million request.

All of this sounds quite unreasonable. Why should a Congress which appropriates $2 billion for research boggle at granting one one-thousandth as much for basic studies? Is there some reason why Congressmen should be hostile to basic research? The reasons are complex, and they have plagued Bureau directors from the beginning. One of them, of course, is that Congressmen are not scientists, nor is there any special reason why they should understand science.

Dr. Condon, reminiscing, recalled a time when the chief of the Bureau's radio division was on the witness stand, discussing the scarcity of space in the radio frequency spectrum for the many needs of wireless communication. A Congressman interrupted:

"Doctor, I understand that among you scientists there are two theories: some say space is finite, others say it is infinite. I want to know, where do you stand?"

Condon recalls: "The witness started to explain the limitations of using very high and very low frequencies, but the Congressman interrupted him to say, 'No, I mean space, you know, *space*,' making a large and globular gesture toward the part of the three-dimensional continuum in front of him.

"The witness squirmed and looked at me for guidance, quite willing to make it finite or infinite for the sake of the budget, but I could only indicate with a gesture that I did not know which was the preference of that particular Congressman. So he gulped hard and said, 'I think it's infinite.' 'Thank you very much, Doctor, that's all I wanted to know,' replied the Congressman and passed on to another topic."

It is all too easy to poke fun at Congressmen because of the odd notions some of them have about science. But it is a serious and troublesome problem, to which no solution is evident. A Congressman

must deal with many subjects, of which science is only one. He must also be elected to office, and his understanding of science is not a qualification in which most voters are interested. Nor, for that matter, are many interested in his record of supporting science while in office.

Whether they understand science or not, Congressmen decide how much shall be spent and for what kinds of research. Representatives of federal agencies appear before appropriations subcommittees to defend their budget requests, but the give-and-take in hearings may have little effect on the outcome. An item which has not been questioned in the hearings may have been knocked out by the committee before a bill reaches the floor for a vote.

Some political scientists think Congress goes too far in tying the hands of the executive branch. The actual invasion of executive powers is greater than the record shows, for appropriations committees have grown so powerful that a federal administrator hesitates to offend a single Member who makes a demand on him. These scientists like the British system, where Parliament appropriates lump sums and the executive allocates them.

But the Constitution gives Congress the sole power to appropriate, and this carries with it an obligation to see that funds are properly spent. Congressional powers have often been used to expose corruption and waste in executive agencies. This might never happen in any of the scientific groups, but they are but a small part of the executive branch.

Congressmen are responsible to their constituents, but it would be unrealistic to expect the voters to demand changes in scientific policies. Much more to the point is the role of the President. Relations between the executive and legislative branches are fluid. The President has tremendous influence on Capitol Hill if he elects to use it. If any President should give a high priority to basic research, he could probably win Congressional approval of any reasonable budget he submitted.

While the National Bureau of Standards has not had such Presidential backing, it has enjoyed reasonable stability. Its most serious setback came in 1933, when Franklin D. Roosevelt, in one of his first actions as President, slashed its budget in half, forcing dismissal of more than a third of its staff.

The Bureau has, as a rule, been remarkably free from political pressures. Bureau directors have been chosen without regard to political affiliation. All have been able scientists respected by their colleagues. Seldom has anyone in the administration or Congress attempted to suppress or influence the findings of Bureau research.

Against this background the AD-2X affair, which came to public attention in 1953, was more shocking than budget cuts and more threatening to the Bureau's future. The public record was made, largely, before the Senate Select Committee on Small Business. It might have been just another hearing. But at the very outset the secretary of commerce announced that he had lost confidence in the Bureau and its work.

AD-X2 is a battery additive, sold by a company known as Pioneers Inc. The Bureau has tested battery additives from time to time in the course of its electric battery research. In 1931 it published a circular summarizing its findings: no additive it had tested materially improved battery performance or longevity. After additional tests, the circular was reissued in 1949.

Jesse M. Ritchie, president of Pioneers, was unhappy about this circular. He and his associates asked, demanded, and insisted that AD-X2 be specifically exempted from the Bureau's statements.

The Bureau had, in fact, tested AD-X2. Ordinarily it does not mention brand names. But the National Better Business Bureau reported that AD-X2 promoters were claiming the Bureau had *not* tested AD-X2, and hence the circular did not apply to their product. Asked to verify this, the Bureau said AD-X2 was one of the brands tested. In 1950 and 1951 further tests were made at the request of the Federal Trade Commission and Post Office, both then considering action against AD-X2.

Then the pressure campaign began. Within a few weeks the Bureau was questioned about AD-X2 by twenty-eight Senators. The sudden interest was explained by a memorandum sent from "Battery AD-X2 Plant No. 236" to battery distributors, which said, in part:

> "We are now trying to bring to bear sufficient pressure to cause a Senate investigation of the National Bureau of Stand-

> ards. We certainly have reason to believe that an investigation and perhaps a shake-up are in order. A few days ago, about the time that all distributors of Battery AD-X2 were writing their Senators, Dr. Edward U. Condon, for many years the Director of the National Bureau of Standards, suddenly resigned. We believe that this is significant, and we like to believe that we had something to do with the resignation."

Mr. Weeks had not then become Secretary of Commerce. There is not the slightest evidence that Condon's resignation was affected by Mr. Ritchie's campaign. But in 1953 it was a different story. When the Post Office held a hearing on AD-X2, Pioneers Inc. chose not to appear. In February 1953 the Post Office issued a fraud order, denying Pioneers the use of the mails. Suddenly Secretary of Commerce Weeks and Senator Thye of the Senate Select Committee on Small Business intervened on behalf of Pioneers, and the fraud order was suspended a week after its publication. A few days later, Secretary Weeks demanded that Bureau director Allen V. Astin, Condon's successor, resign.

Weeks accused the Bureau of "refusing to run tests which would show that his (Ritchie's) product was different from previous additives tested and had merit." He accused Bureau scientists of working closely "with individuals and organizations who might have had an interest in the final outcome," presumably battery manufacturers.

"I know that this business has suffered severely at the hands of certain bureaucrats," Weeks declared. "As a practical man, I do not see why a product should be denied an opportunity in the market place." He directed that the Bureau's circular on battery additives be impounded.

Astin's forced resignation became front-page news, and scientific groups sprang to his defense. Secretary Weeks became the target of the month, and newspaper editorial opinion was predominantly against him. He asked the National Academy of Sciences to appoint a committee to investigate the matter. But he insisted that Astin's dismissal would not be reconsidered, no matter what the committee found.

The Senate Small Business committee opened formal hearings in June 1953. Ritchie's testimony alone filled two hundred pages. By the

time Director Astin took the stand, the issue was plain. This was not a struggle between sin and virtue, or, for that matter, between AD-X2 and the Bureau, nor even between Secretary Weeks and his critics. This was something much more fundamental. It was science versus non-science.

Ritchie made no serious attempt to explain *why* his product had merit, or *how* it affected batteries, nor did he offer laboratory evidence of its value. He had something that impressed several of the senators even more: testimonials, hundreds of testimonials, from satisfied users of AD-X2.

For example, there was a letter from the general manager of the Good Humor Corporation in Newark, New Jersey: ". . . we are more than pleased with the results . . . we have ordered you to treat our whole fleet."

Astin had rough going when he took the stand. Senator Thye declared himself quite plainly:

> "All I can do is to look at the financial sheet of a man who had a record of what it cost him to service that fleet of batteries over a period of years and what the cost was after he used the compound. Those are the cold facts which I can look at and understand, but I do not know a blessed thing about it when you start talking about the technicalities of a two weeks' laboratory test . . ."

Again and again, replying to the same question asked in a variety of ways, Astin tried to explain the meaning of scientific evidence:

> "Many people think that the laboratory test is a sort of theoretical test and that the field test is a practical test. Now, I believe that the reverse is actually true, because in the laboratory test it is possible to make with much greater accuracy and control the measurements by which the comparisons between the two groups of samples can be compared. In the field test, additional variables are introduced."

With evident reluctance, he answered questions calling for speculation: Why did some people believe AD-X2 worked? He suggested

possibilities. For example, a battery which is properly cared for will last longer than a neglected battery. If someone who has been neglecting battery care begins using AD-X2, and *also* begins to give better general maintenance, better maintenance alone may explain the improved results. But he returned again and again to his basic point: ". . . one cannot ascribe a particular result to a particular action unless you know what would happen if that action had not been performed." Scientific evidence requires comparison of identical batteries under identical conditions, one group treated, one untreated.

Certainly Ritchie's testimonials were impressive. But what did they mean? If AD-X2 worked, why did it work? Why did repeated tests, under controlled conditions, fail to show any significant effect? To anyone with scientific background, Astin's case was unimpeachable. But some of the Senators, at least, agreed with Senator Thye when he summed up his feeling: " . . . the proof of it lies in that bundle of purchase orders . . ."

The Senate committee heard 785 pages of testimony and adjourned without further action. But the committee appointed by the National Academy of Sciences reached an emphatic conclusion: "The quality of the work of the National Bureau of Standards in the field of lead acid storage battery testing is excellent. This statement is made without reservations." In due course, Dr. Astin was reinstated as director. Mr. Ritchie ran for Congress in 1954 and was soundly defeated. The Bureau's circular on battery additives is still impounded, no longer available to the public, and it will probably remain so. As this chapter is written, the AD-X2 case is still before the Federal Trade Commission. Secretary Weeks has become a strong supporter of the Bureau and of Dr. Astin.

But the issue which underlay the AD-X2 affair has not been resolved, nor will it soon be, in any fundamental sense. Perhaps the issue was always present, but it has been felt much more keenly, in many ways, since the scientist became "the indispensable warrior," and since science came to have such a vital role in both peace and war.

It is the conflict between scientific evidence and a sheaf of testimonials, between knowledge and belief, between the scientific man and the "practical" man. Of the questions men and societies encoun-

ter, many cannot be answered with scientific precision. In economics, politics, industrial management, and other social sciences many decisions can be made only on the basis of experience, judgment, opinion and reasoning.

The scope of the exact sciences has broadened, however, and there are more and more questions which can be answered by scientific method. The discipline of science is severe. It leaves no room for exceptions, for opinions, for wishful thinking. The awkward fact cannot be swept under the rug. The scientist asks: what happens? why does it happen? does it *always* happen under those conditions? Science accepts nothing as fact until it has been exposed to all scientists, for them to test and attack. A single exception disproves the rule.

Science cannot now and probably never can supply so firm and rigid a structure for, say, human relationships. But it has driven out beliefs to which men clung for many years, despite proof to the contrary: that the earth was flat; that heat was fluid; that man could never fly.

Of course matters might right themselves in time. The disturbing question today, though, is whether there *is* time. There has always been a conflict of ideas between the scientist and the non-scientist. Today the issues lying between them concern survival.

What are these issues? First, money. Scientific research is no longer something a poor man can do in his attic. The tools of science—the atomic pile, the electron miscroscope, the electronic computer—are costly. Research costs millions of dollars. Control of funds for such research is largely in the hands of non-scientists. The result is prolonged neglect of fundamental research, emphasis on the "practical," the projects where results can be specified in advance, and on military research.

Dr. Condon declared: "Today every activity of Government is being adjudged solely on the basis of its contribution to defense." In scientific research, more than 85 percent of federal funds are assigned to defense projects. The balance is scattered thinly over the whole range of scientific work in agriculture, medicine, civil aviation, housing, the social sciences, communications, natural resources, education, and fundamental research in the physical sciences.

The starved areas, in short, are those with the greatest potential for advancing human welfare. Many a biologist has found, to his dismay,

that he can enjoy a better income and better research facilities if he is willing to do research on bacteriological warfare rather than trying to do something about cancer.

Money and manpower is only a part of the problem, however. Because most of the money goes into military research, a large part of present-day research is secret, and the scientists engaged in it are working under conditions new to science and to America. In the past, scientific communication was free. A scientist was known to his fellows by his publications. The first step in any research undertaking was to search the literature so all accumulated knowledge could be brought to bear on the problem and needless duplication avoided.

No one denies that secrecy is necessary. But "secrecy" and "security" have become such powerful instruments that their purposes and consequences are often forgotten. Ideally, a security system would deny information only to a potential enemy. Practically, this is simply not possible. If a secret is to be kept, knowledge of it must be limited to a very few persons, and those persons must be under the direct supervision of the security machinery. To keep secrets from enemies, they must also be kept from friends.

The result, of course, is a sometimes fantastic duplication of effort. Research projects have at times been stalled for months, for lack of information which a nearby research group could have supplied.

Military research administrators have struggled with the problem, and a vast amount of military research information has been declassified, with benefit to civilian science. But, conceding the necessities and the good intentions, there is no such thing as a good security system, even with the best administration. Scientists have had frequent reason to object to the way the system has been administered. Decisions are often made by administrators who are not scientists. A man charged with responsibility who lacks knowledge will err on the safe side. Inevitably there are absurdities, like the security officer who placed his "Secret" stamp on a table of atomic weights. The same table appears in high school textbooks.

On the other hand, the most strategic information is often not a scientific formula or the design for a new device. It may be of greater significance for the opposition to know, broadly, what lines of research

we are pursuing. This is the most difficult kind of information to conceal. It may be deduced from pieces of information which are innocuous, if taken individually, such as the employment of a top-flight scientist with a known specialty.

One of the appalling things about secrecy is that one never really knows when it is necessary, because one does not know how much the opposition knows. Let us take an imaginary Project X, a secret research undertaking of several hundred scientists, behind tight security controls. Let us assume that a similiar Project X in the Soviet Union was successful some months ago; our Project X has not yet reached the same point. In short, there is nothing behind the walls of our Project X which is not already known to Soviet science. But because we do not know that, we must maintain our tight controls, and deny information to other scientists in the United States and in friendly nations, information which might be of value in non-military research.

With the possible exceptions of incorrigible adolescents who enjoy playing cops-and-robbers, no one likes or wants a security system. It is a bitter necessity, and so long as the necessity exists there will be pain and conflict, and science will work under handicaps. The handicaps could be accepted more philosophically if it were only information that came under control. But the controls affect people, and the scientific community has been deeply shocked and aroused by the damage done to some of its most respected leaders.

Some cases are well known: those of J. Robert Oppenheimer and former Bureau director Edward U. Condon. Hundreds of other cases have not come to public attention, but they are well known to scientists, for their colleagues have been affected. It would be difficult to find a laboratory in government, or a government-subsidized university project, where one or more scientists have not been fired for "security" reasons.

It is enormously significant that in a majority of these cases the men attacked still have the confidence and support of their colleagues, a support that is almost unanimous. After Condon had been under fire from Capitol Hill, he was elected president of the American Association for the Advancement of Science, one of the nation's oldest and most conservative scientific organizations. A few weeks after his Navy

clearance had been suspended in what was widely interpreted as a bit of 1954 pre-election campaign strategy, Condon was given a standing ovation when he appeared at the A.A.A.S. annual meeting.

Such cases are regarded by many observers as evidence of a deep-rooted conflict between the scientific community as a whole and those who now so largely control science. For science is controlled today, as it never was in the past. Government money has been poured into university, private, and industrial laboratories, and the government's own scientific establishment has grown. Wherever the scientist goes, he is likely to be working for the government, directly or indirectly.

Scientists are disturbed by the extension of security procedures far beyond the range of secret military projects. Even if a man works on wholly unclassified work, he is not immune. The United States Public Health Service has refused grants for medical research because of unspecified "derogatory information" about a medical research worker. What happens to a man on the staff of a university clinic, when, because of his presence, the government refuses to grant to the clinic funds for research?

The matter is desperately serious. The American Association for the Advancement of Science put aside its long-standing aloofness on political matters to demand changes in security procedures. Vannevar Bush, for years a most effective intermediary between government and science, declares the system has become disruptive, driving a wedge between military men and scientists that could have appalling consequences.

People sometimes ask, "What's so special about scientists? Why do they feel they're entitled to special treatment?"

That isn't the point; and the point is seldom mentioned in all of the discussion that has occurred. There is one reason why the scientist, of all people, does have a special attitude about security cases. Because he is a scientist, he has been trained in scientific discipline, and an essential part of that discipline involves the use of evidence. He is trained to recognize facts, to reject non-facts, to draw reasoned conclusions from the facts, and not confuse facts with wishes, hopes, fears, or conveniences.

This same procedure, in theory, is used in security cases. Evidence

is gathered and sifted, non-facts are rejected, facts synthesized, and the synthesis compared with positive and definite standards. Whether this could ever be done satisfactorily by any set of men under any circumstances is debatable. That it isn't done today is notorious. There are no positive standards. Men considered good security risks in the State Department have been turned down, on the same evidence, by the Department of Agriculture and—believe it or not—the National Park Service. Men singled out as political targets have been given "clearance" after "clearance" until, finally, a review board came up with the damaging answer sought by the attackers. Men have been publicly disgraced and their careers ended by decisions based on nothing better than rumor, gossip, supposition and inference. This man has a relative in Russia. That one had a college roommate who read subversive literature. Another went dancing with a girl who later married a Communist.

It's hard to say which stimulates the greater resentment: the transparent outrages or the incredible absurdities. One prominent scientist, for example, was told that his request for a research grant would be turned down if his own name were signed to it. But if he had his assistant sign the request, it would be granted! He did and it was.

Scientists have the ordinary human reaction to such matters. But beyond that normal reaction, men apply their own training and disciplines. Politicians, for example, may dismiss such cases as political expedients or necessities. When the scientist imposes his dicipline, the scientific discipline in the use of evidence, his reaction is likely to be incredulous fury. Whatever else one may say about security and secrecy, the methods of reasoning in vogue violate every scientific precept.

Scientists are also aware, from reading scientific history, that their calling flourishes only in an atmosphere of intellectual freedom. The loyalty-security program, the barriers erected between scientists in different countries, the words *secret* and *confidential* stamped on scientific documents, the guarded gates, the locked filing cabinets, the security investigators masquerading as everything from vacuum cleaner salesmen to personal friends, the warning signs on the bulletin boards, the interrogations about the sexual habits of colleagues and acquaint-

ances, the need to justify every new research project on military grounds—these and other prevailing conditions are not, in the opinion of scientists, the formula for intellectual freedom and scientific progress.

Many scientists have made a quite personal decision. Government, as an employer, is a bad security risk. Surveys show that the percentage of scientists willing to work for the government or on government contracts has dropped sharply, and the reasons given for refusal are those just mentioned.

But even those who agree that, in these troubled and dangerous times, all present restrictions are necessary, and who may, indeed, support them vigorously, wonder: How long? For it can only be an expedient, not a system to live by. And if it is prolonged, the loss to the country, in terms of scientific knowledge alone, may far outweigh the diminishing sum of exclusive knowledge we try to protect.

The National Bureau of Standards has had its two most recent directors attacked. Dr. Condon was accused of being the weakest link in our security system by a Member of a Congressional committee which refused to hear him testify under oath in his own defense. He was never formally accused before any competent tribunal, but the sniping continued even after he had left the federal service, causing him to resign from an industrial research directorship. Dr. Astin was attacked in the AD-X2 case.

Still, the Bureau has fared somewhat better than most federal agencies. There have been no sensational charges against other staff members. Undoubtedly some staff members have been fired or asked to resign, but no one will say how many, and present staff members seem to feel that the Bureau is a better place to work than most government laboratories. Now that most secret research has been transferred out of the Bureau, something of the pre-war atmosphere has returned. With no secrets to keep, Bureau scientists can talk freely to visitors, write papers for publication, take part in discussions.

Security, secrecy, and the AD-X2 affair, the attitudes of Congressmen and the state of basic research—these are not separate issues but part of one large problem. Some say they are symptoms of world tension. Others see an upsurge of anti-intellectualism, the rise to popular favor of "practical" men who ridicule science, art and letters.

Even if the danger of war should abate, even if the elaborate security apparatus were to be put aside as no longer needed, even if the scientific resources of the country were not so monopolized by military research, the essential problem would remain. For in a mere half-century this world has been transformed by science, the changes transcending those of all earlier history. The number of scientists has vastly increased, and the role of the scientist has been profoundly altered. He is not only the indispensable warrior. Today he is the indispensable civilian. In peacetime, as well as in war, he holds the power of life and death.

The very people who ridicule science are among those who assume, blindly and blithely, that science is the answer to everything, and that any human need or desire can be met. So the scientist, once an isolated philosopher inquiring into the properties of nature, whose work was often neglected for generations, is now called upon to provide miracles to order. New knowledge is demanded of him. He is hired and subsidized and given questions to answer. He is asked to build a satellite to revolve in an orbit around the Earth, to make barren earth yield crops, to change the weather, to find a cure for cancer, and to find a substitute for petroleum.

The scientist himself has had too little time to think about his new role and how he fits into society, what to make of his larger influence and prestige. He has been caught up in a boom, a crescendo which began in 1940, and has yet to reach its peak. Nor has society had time to appraise the scientist in his new role, understand him, evaluate his contribution.

Inevitably there have been miscues. Some scientists have come out of their laboratories and plunged into politics without first learning the rules of the game. Some politicians have suggested that scientists ought to stay with their test tubes and leave serious matters to others. Yet scientist and politician can no longer ignore each other. Like it or not, they have become interdependent. They must learn to understand each other and integrate their disciplines or the consequences will be catastrophic.

In his excellent *Government and Science* (New York University Press, New York, 1954) based on his 1953 James Stokes lectures at

New York University, Don K. Price says: "In recent years we have built on these foundations a markedly new system for the support of science—a system that has produced results as terrifying as they are effective. Whether we have at the same time developed an ability to understand where this system is going, or to control it, is another question."

14

NEW STANDARDS

On the morning of October 19, 1954, Mr. A. J. Keen, meter superintendent of the Potomac Edison Company of Hagerstown, Maryland, drove to Washington. Shortly before noon he arrived at the east building of the National Bureau of Standards, carrying a small mahogany case. In the case, cushioned with sponge rubber, was a General Electric Company Type 1B-10 Rotating Standard Watthour Meter, serial number 3059661, coming to the Bureau for its semi-annual check-up. Had Hagerstown been further from Washington, Keen might have sent his instrument by express, or had it checked by a university or commercial laboratory. As it is, he makes occasional business trips to Washington and brings the meter along.

When the testing order had been recorded, the Chief of the Electrical Instruments Section, F. M. Defandorf, sent the meter down the hall to F. D. Weaver, Laboratory Superintendent, who noted the series of tests Keen wanted and put the meter on his testing schedule. Preparation for the test began at 8:30 a.m. on October 24th. While Weaver prepared the apparatus, his assistant, Rita McAuliff, pulled from the files the history of this particular meter.

The official report to Potomac Edison began: "The voltage circuit of the meter was energized for one half hour before the test, and the test runs were of 100 seconds duration . . ." Keen's meter is not unlike the rotating watthour meter in your home, which measures the household use of electric power. Such a meter must register accurately at

minimum and maximum loads, and points between, whether you have a single lamp burning or every appliance in the house turned on.

Keen's order specified 14 check points. Weaver made three tests at each point, a total of 42 test runs. Actually he made 45, because the first reading on the first run seemed a little out of line, making him suspect that the test apparatus had not yet warmed up fully. Miss McAuliff noted the readings as Weaver reported them. With time out for lunch, they finished the test runs at 2 o'clock. It took another hour to compute and check the averages, tabulate them, compare them with previous tests, and prepare the official report.

The tests showed Keen's meter was accurate to within a half of one percent. If he wished to do so, Keen could adjust it, or have it adjusted by the manufacturer. There would be no need to do so, however; it might be better to make no adjustment, but to correct future readings according to the Bureau's findings. The test cost Potomac Edison $71. The meter was ready for Keen to pick up on October 25th.

Keen is responsible for the accuracy of some 20,000 watthour meters in homes, stores, factories and other places served by his company, and each meter determines the size of a customer's bill. In the United States, there are about sixty million such meters. If all should be fast or slow by one percent, customers would be overcharged or undercharged by four billion kilowatt-hours of electricity in one year.

Keen's meter is the standard instrument for his company. Though portable, it never goes outside his laboratory, except for its trips to the Bureau. Company working standards, used by inspectors and technicians, are brought to the laboratory for comparison and adjustment. These working standards are used to check meters in customers' homes.

In recent years there has been much new construction around Hagerstown, so Potomac Edison has bought several thousand new meters for customers. Each was tested before it left the factory. The factory inspectors used working standards which are checked from time to time against a master instrument in the company laboratory. This master instrument, like Keen's is periodically checked at the National Bureau of Standards or some commercial standardizing laboratory.

In the United States there are several thousand watthour meters used as company or laboratory standards. Only a few of these are ever

sent to the National Bureau of Standards for checking. But the standard is well established. There are frequent occasions when secondary standards are intercompared, and any discrepancy, should one arise, would be settled by reference to the national standard. Incidentally, Keen's meter was not certified as "correct" or "incorrect." The Bureau's report gave precise comparisons between its readings and the national standard.

The kilowatt-hour is a good example of a modern unit of measurement. The traditional units, such as the foot and pound, can be preserved as physical objects, in a vault. But one cannot store away a kilowatt hour. It is an event, not an object. Many other quantities which science and industry measure today are phenomena unknown or unrecognized a few generations ago. Others, such as temperature, were known but men had no way of measuring them.

Modern measurement is also concerned with the properties of materials. Here the modern housewife is not much ahead of her predecessors; in cooking, she is aware of numerous properties of materials, but she cannot measure them. When she whips egg whites, mixes a batter, kneads dough, or rolls piecrust, she observes properties which she calls stiffness, dryness, glossiness, thickness, elasticity, stickiness, resilience, flakiness. She recognizes the difference between a thick and a thin mix, but she could not grade thicknesses numerically.

Yet such properties of materials can usually be measured. Indeed, accurate measurement of them is essential in science, engineering, and industrial production. In an oft-repeated (and oft-misquoted) quotation, Lord Kelvin said that to understand something one must be able to measure it. There is more meaning in his statement than first appears; because, before one can do any measuring, one must first decide what should be measured, what is significant, and how to isolate the significant quality from others.

Suppose, for example, one had a long and rather slender rod of unknown composition. To study it, one might first measure its length, diameter, and weight. What then? To study the properties of this rod, one would undertake a series of measurements and tests. First, perhaps, it would be measured at different temperatures, to determine its coefficient of expansion. From volume and mass its specific gravity

could be computed. Its thermal and electrical conductivity could be found, and its heat capacity. Later, when one could take a piece from the rod, its melting point could be determined. Thus far the measurements have been familiar, combinations of familiar units, such as coefficient of expansion, a combination of length and temperature measurements. Now one would begin studying its "strength," a word with many meanings. What happens when one attempts to bend the rod? It may be rigid and unyielding, or it may bend readily. It may shatter; it may be springy, bending easily but returning to its original position when the pressure is released; or it may bend and retain its new shape. One might attempt to elongate the rod, with a number of possible results: breaking, returning to its original length, or stretching and remaining stretched.

Other tests would determine the ability of the rod, in a vertical position, to carry a load; what happens to it when it is twisted; what happens when it is subjected to vibration or shock, or to extremes of heat and cold.

If one were to begin such tests in a well-equipped laboratory, the task might soon appear endless, for the more one tested, the more questions would be suggested. Having run one series of tests at room temperature, one would wonder: Would the results be different if the temperature were different? Or: What would happen if this bending force were applied not just for a few minutes but for a period of weeks or years? Or: What would be the result of subjecting the rod to two different stresses at the same time? Nor, indeed, could one confine his curiosity to the properties of this particular rod, or, rather, to a number of identical rods, for by now a great many of them have been used. What would be the effect of using a rod with twice the diameter? Or rods with different cross-sections?

Though such research may seem endless, this is the very stuff of modern engineering. An engineer could not design a suspension bridge without knowing what to expect of his materials: how thick the cables should be, and of what materials and designs; how to draft the specifications for supporting columns; and so on. He must calculate what heat and cold, traffic, wind, and other conditions the structure must withstand, and specify his materials accordingly.

In what units are such tests and measurements made? Usually in

terms of familiar units. Force may be measured in pounds; work in foot-pounds; rate of work in foot-pounds per second. Pounds are used to measure the ability of a column to withstand loading. The extent of twisting or bending will be measured by the degrees of a circle.

In examining the properties of a material object, the problem is not to make measurements. One could think of a great variety of measurements that could be made. The challenge is to find significant measurements. Suppose the rod has a one-inch diameter. By testing this rod, can one assemble data which will permit accurate prediction of the performance of a two-inch rod?

One relatively new measuring standard is *viscosity*. Everyone knows some liquids are thicker than others. A crude measurement of thickness could be made with a funnel and a stopwatch. First, a measured quantity of water would be poured into the funnel, and the time required to empty the funnel would be measured. Then other liquids would be poured through: corn syrup, milk, motor oil, paint, cough medicine. Water might be taken as the base point and its time taken as 1.0. A thicker liquid might be given a thickness value of 2.8, if it took 2.8 times as long as water to pass through the funnel.

If you were a scientist, you could not stop with one experiment. Next you would make runs with a funnel having a larger neck. Perhaps you would approach this test with some hypothesis in mind: that, for each fluid, rate of flow is in direct proportion to the squared diameter of the neck. But if you did, the results would be disappointing. The hypothesis wouldn't be substantiated. The ratios you determined in your first experiments would not stand up. By repeating such experiments, changing the conditions each time, you would eventually conclude that rate of flow is not determined by a single factor, such as "thickness," together with the size of the aperture; but that liquids have a number of properties which vary independently of each other.

So this problem can not be settled as easily as you might have thought. But don't be discouraged! On the contrary, if you are a scientist such complications are just the opposite of discouraging. By measurements you have shown that a familiar phenomenon has some puzzling aspects. By making more measurements, under many different conditions, you can elaborate upon the puzzle. In time, by making

more and more measurements, you may discover basic relationships that add to knowledge of the properties of matter. You will find that rate of flow is affected by temperature, for example. Also, if you time the flow of one cup of a liquid through the funnel, then pour two cups into the funnel, the emptying time will not be precisely doubled.

Such experiments were actually made some years ago. Then the experimenters began to theorize. If a drop of water is allowed to fall freely through space, its rate of fall is the same as if it were a solid object. Drops of any fluid fall at the same rate.

But if a drop of water is placed within a vertical capillary tube, a glass tube with a fine hair-like bore, it will not fall, but remain motionless in the tube. So experimenters reasoned: The flow of water in a tube of larger diameter is in response to the influence of gravity, but it is limited by the force which holds a drop inside a capillary tube.

Could this force be measured? Why not? They set up apparatus to measure the pressure required to force liquids through capillary tubes, noting the differences among liquids.

About 1838 a Frenchman, Jean L. M. P. Poiseuille, made the first systematic investigation of the flow of liquids in capillary tubes. In time he found that his experimental results could be brought together in a formula:

$$\frac{Q}{t} = \frac{\pi P d^4}{128 \mu l}$$

Looks complicated? It isn't, very. "Q" is the quantity of liquid discharged from the capillary tube in a certain time, "t." π is the familiar *pi* with the same value it had when you were in school, 3.1416. "P" is the difference in pressure between the two ends of the tube, actually the pressure added at one end to cause the liquid to move. The "d" is the diameter of the tube, and "l" is its length, while μ is the subject of the experiment, the viscosity of the liquid, its internal resistance to flow.

What does the formula mean? First, Poiseuille identified the factors affecting the rate of flow of liquids in a capillary tube: pressure, diameter of the tube, length of tube, and the liquid's internal resistance to flow.

Second, he found that various liquids have characteristic viscosities,

which may vary with changes in temperature, for example, but which are always the same under identical conditions.

Third, having not merely identified the variables but determined how each affects rate of flow, mathematically, Poiseuille could determine the viscosity of a liquid.

Suppose you wish to repeat his experiments and confirm his formula. You set up your apparatus: capillary tubes of known lengths and diameters, a means of applying and measuring pressure applied to one end of a tube, a receptacle to catch and measure the quantity of liquid discharged from the other end, and a timing device.

Perhaps you begin with water. You apply a constant pressure for a fixed period of time and measure the quantity of water discharged.

Next you double the time; if the formula is correct (and your technique is correct), "Q," the quantity of water discharged, should be doubled too.

Now you double the pressure. Again, if everything is in order, "Q" should be doubled.

Now you substitute a capillary tube with a diameter twice that of the first one, and repeat the experiments. According to the formula, this should multiply "Q" by sixteen; sixteen times as much water should be discharged. On the other hand, if you double the length of the tube, only half as much water should be discharged.

Of course, you will not be satisfied to ascertain that the formula is valid for water only. You will spend several days on experiments with water. Then you will make similar runs with other liquids, to make sure the formula describes their behavior also. Only when you have done this will you have sufficient confidence to make comparisons between the viscosity of water and the viscosities of other liquids.

Indeed, if you are going to be really scientific and careful about these experiments, so you can report the results with professional satisfaction, there are preparations to make before your experiments begin. Your instruments, with which you measure mass, volume, length, and time, must be carefully checked against standards of known reliability. You will need a piece of apparatus to apply pressure to the tubes, and a way of measuring pressure in pounds-per-square-inch or grams-per-square-centimeter. This measuring instrument must be accurately

calibrated. The apparatus must be designed to apply the desired pressure accurately and evenly.

You may spend several days investigating capillary tubes for the experiment, making sure the diameters of their bores are constant throughout their lengths. You might be able to find such tubes today, but when the National Bureau of Standards undertook some experiments with viscosity in 1931 there were no tubes with uniform bores available in the United States. Several months were spent seeking a way of making such tubes. Later they were obtained from a German manufacturer of laboratory glassware.

Eventually you are ready to begin. But throughout your work you must be alert to every possibility of error caused by variables outside the scope of the experiment. Temperature, for example, must be kept under tight control. Even in an air-conditioned laboratory some temperature variations may occur; and if the room should become one or two degrees warmer, the experimental apparatus will be affected.

How careful must you be? That depends on the accuracy you hope to achieve, of course. Here is what two Bureau scientists, N. Ernest Dorsey and Churchill Eisenhart, writing in *Scientific Monthly* for August, 1953, have to say about attempts at absolute measurement:

> "Having found that the apparatus seems to be working properly, he (the experimenter) will change, one by one, and by known amounts, each of the adjustments, and will note how each change affects his observations. If possible, he will carry each maladjustment to a point where it produces an easily measurable change in his observations; and if maladjustments in both directions (positive and negative) are possible, he will similarly study each. Thus he will find how important the several adjustments are, the accuracy with which they must be made, and perhaps how to detect each maladjustment experimentally and to correct for the error it produces.
>
> "Readjusting the apparatus, he will proceed to change, one by one, every condition he can think of that seems by any chance likely to affect his result, and some that do not, in every case pushing the change well beyond any that seems at all likely to occur accidentally.

"There still remains the possibility of systematic errors arising from unsuspected causes, from secular variation in laboratory conditions (temperature, humidity, light, vibration, etc.), possibly from solar, lunar or atmospheric effects, etc. So the observer will take long series of observations, extending over weeks, months, or years, noting carefully everything that seems either pertinent in itself or of assistance in fixing the attendant conditions. These will be worked up, day by day, carefully compared with one another, and probably plotted in such a way as to show clearly any change that might appear. From time to time changes will appear, and will be studied."

So, if you really want to know something about viscosity, it would be well to allow plenty of time for your studies, not just a few months!

Poiseuille himself, extending the scope of his experiments, found that his equation failed to describe the behavior of liquids in very short tubes when the velocity was high. About 1890 another French scientist, Maurice Frederic Alfred Couette, elaborated the formula to correct it for "end effects." An English scientist discovered that after a certain velocity is exceeded the equation no longer applies, and beyond this point the flow in the tube is turbulent or hydraulic, rather than viscous.

Research in viscosity has continued and broadened. Before the twentieth century began a definition of viscosity was generally agreed upon: "the force which will move a unit area of plane surface, with unit speed, relative to another parallel plane surface, from which it is separated by a layer of the liquid of unit thickness." The unit of viscosity was named the "poise" after Poiseuille, and defined as "1 dyne-second per square centimeter."

The need for a national standard of viscosity caused research to begin at the National Bureau of Standards soon after the laboratories were built, but World War I interrupted. Postwar industrial development made such a standard urgently necessary.

The instruments in use for measuring viscosity were notoriously unreliable, subject to error because of leakage, bubbles, errors in filling, improper cleaning, temperature variations, and other conditions.

The Bureau tested many types, and improved varieties were manufactured according to Bureau recommendations.

Fixing a national standard by absolute measurement was a larger undertaking. In 1918 the absolute viscosity of water at 20 degrees Celsius was taken to be 0.01005 poise. But values found in later experiments differed by as much as 4 parts in 1,000, a large error indeed. In 1931 a new research project began at the Bureau, with the objective of determining this value with an accuracy of at least 1 part in 1,000.

Technical difficulties and restricted budgets caused many delays and interruptions. Not until 1938 were two men able to work on the project consistently, until World War II brought it to a halt again. After the war, work was resumed, and the experimental phase was completed in 1947. There remained the immense task of analyzing the data.

The findings were published in 1952, but before that time the matter had been discussed by scientific and standardizing organizations around the world. Formal adoption of the new standard was delayed at the request of the American Society for Testing Materials and the International Organization for Standardization, so that all members could make the change at one time.

In July 1953, American science and industry formally adopted a new standard of viscosity: 0.01002 poise for the absolute viscosity of water at 20 degrees Celsius. The national physical laboratories of England and Germany adopted the change on the same date. It was a large enough change to require the adjustment of thousands of viscometers and correction of published tables in standard reference works. Viscosities of other liquids are determined by comparison with water.

Industrial technicians make many viscosity measurements every day, so they need instruments which are accurate and quick, as we have noted. Some types of viscometers, such as those used in the oil industry, are sufficiently accurate for ordinary needs. But in the growing synthetic rubber industry, the best available commercial instrument, the Mooney viscometer, wasn't good enough. The viscometers in use had not been standardized; the results obtained with one instrument were not reproducible. Data gathered in one laboratory could not be

compared with data obtained elsewhere with assurance that the comparisons were valid.

So, late in World War II, the office of the rubber director asked the Bureau to design a better device. Bureau men developed a new design standard for the Mooney viscometer, standard procedures for its use, and procedures for its adjustment and calibration.

Then new types of synthetic rubbers came along, with higher molecular weights, and again viscosity measurements gave trouble. The Mooney viscometer has a flat rotor, which revolves within a sample of the material, pressed between dies. Smooth rotors were satisfactory for most commercial rubbers, but with the new types of rubber enough slippage occurred to distort readings. Bureau investigations found that slippage depended not only on the mechanical nature of the surface, but also on its chemical composition, and on the speed of the rotor. In 1954 plans were published for an improved Mooney viscometer. But the problem isn't solved yet. "Results for rubbers of extremely high molecular weight . . . must be interpreted with caution," the Bureau warned.

The national standard of viscosity is one of several hundred standards in use today, standards which set the framework of measurement and testing for all science, industry, and commerce.

If you were painting your living room, you may be content to choose the color by eye, perhaps do a little mixing to get the shade you prefer. You can also judge, by eye, whether a light is bright enough for reading or working. You set the volume control of your radio by ear, sweeten your coffee to taste. The cook makes many judgments by eye and by feel: the thickness of batter or gravy, the brownness of fried potatoes, the resilience of a baking cake.

Industry, on the other hand, cannot judge. It must measure. Producers of paint, printing inks, dyes, and other coloring materials are expected by their customers to maintain unvarying color standards, year after year. Lamp bulbs must meet standards of illumination. From raw materials to finished products, process control and inspection, in any industry, is a series of measurements against standards.

The national standard of candlepower, for example, is a set of incandescent lamps, calibrated for candlepower and luminous flux

against a black body. The standard of brightness is defined as the intensity of radiation from the interior of a black body at the temperature of pure platinum at its freezing point. Other lamps, used as working standards, are compared with this set periodically.

Thanks to this standardization, an engineer can manipulate light. In your own home, you might be satisfied to experiment with lamps of various wattages until it seemed that the living room had both good general illumination and good reading light. The architect-engineer has little opportunity to experiment in planning a new factory; sizes and locations of lighting fixtures are specified on his drawing board. He can turn to a reference book for information on good lighting standards, recommended by the Illuminating Engineering Society: 50 foot-candles for bookkeeping and typing; 20 for rough bench and machine work; 20 plus specialized supplemental lighting for fine assembly; 5 for stairs and passageways. He can order lighting equipment by specification. Later, when it is installed, he can use a pocket light meter to inspect the results. I.E.S. standards, manufacturers' specifications, and his meter—all are linked to the national standard of candlepower.

Underlying the whole array of national standards are the three fundamental ones: length, mass, and time. Others are derived from these three. In electrical measurement the absolute ampere is derived from the standard of mass; the mechanical force between two parts of the circuit in which the current flows is "weighed" in a balance.

Most of the standards of science are objective; they are defined in terms which do not include an observer. Indeed, one of the problems in absolute measurement is to exclude the effects of the observer's presence, as much as possible. It is a general principle that a quantity cannot be measured without altering it in some way, so that infinite precision is inherently impossible.

A good if rather extreme example of this is in the problem of observing the position and velocity of an electron. No one has ever seen an electron, though the effects of electrons can be observed, as in a cloud chamber.

One might imagine an observing apparatus, though the components are not known today. Of course, if the electron were to be observed and its position noted, say, on a photographic plate, it would have

to be illuminated somehow. Visible light has too long a wavelength. So one might use a source of gamma rays.

But such rays have such high energy that they will affect both position and velocity of the electron thus illuminated. The experiment has altered the conditions. And no one can now explain how the position and velocity of an electron might be observed without such effect.

This is called the Heisenberg principle of uncertainty, and the measurements man makes are quite crude when studied in relation to this principle. But the principle can also be illustrated by some everyday examples. In measuring the flow of liquid through a pipe, any gage inserted in the pipe will affect the flow. Insertion of a thermometer into an area where temperature measurement is desired will slightly alter the temperature. In measuring the neutron flux in an atomic pile, insertion of a detector will alter the flux density so much that a correction factor must be applied.

The human observer is an essential element in another kind of measurement, however, not just an intruder. Color is the response of human vision to different wavelengths of light. When scientists and engineers deal with color, they must consider the observer, for color is a phenomenon which is significant only as it is perceived.

Color can be measured by instruments. White light can be passed through a prism to yield a spectrum. Light of any color, passed through a prism, will reveal its composition by the spread of its components over the spectrum. A device called a spectrophotometer will measure the energy of light at each point in the spectrum, and thus compare the composition of any light with the composition of white light.

But the spectrophotometer and the human eye do not see colors in the same way. To the eye, the color of a sodium flame closely resembles the color of an orange. But analysis by spectrophotometer reveals a radical difference. Light from a sodium flame is concentrated in two narrow regions of the spectrum. Light reflected from an orange covers a larger part of the spectrum and is weak in the very areas where the other is strongest.

Here is a quite extraordinary problem in standards. The spectrophotometer is accurate and useful. It does just what it is supposed to do: it measures relative intensities over the visible spectrum. But its readings do not agree, always, with human experience, with the re-

sponse of the human eye to color. What, then, is the value of classifying colors by physical measurement? For color has meaning and usefulness only as it stimulates vision.

Vision is a response to light, which passes through the cornea and lens of the eye to fall on the retina, a mass of light-sensitive cells. Light causes chemical changes in these cells, which in turn cause nerve impulses to pass through the optic nerve to the brain. Normal human vision is *trichromatic;* there are three types of color receptors in the retina.

In a color laboratory, you would see a device which mixes the three primary colors, red, blue, and green; you can vary the proportions of the three by operating controls. With a little practice, you could match any color by mixing the three primaries. But only by chance could you match a color by mixing only two of the primaries!

That is, unless you happen to be colorblind. Some "colorblind" persons are only partially so; one set of color receptors seems to be lacking. They can match any color by mixing *two* primaries. Such persons are called "dichromats." More severely handicapped are those with monochromatic vision, to whom all color mixtures look alike except in shade.

When you mix colors with this laboratory device and succeed in matching a color swatch, what you have is only an *apparent* match. The spectral compositions of the two may or may not be the same. If they *are* the same, then another observer with normal vision will agree with your judgment. The color match will look right to him, too.

But what if the spectral compositions are not alike? Then, even though the color mixtures look alike to you, they may not look alike to another observer! Human color vision is not exactly standardized.

The old system of matching colors by experiment thus had an odd limitation. A man who mixed colors might insist he had matched the color sample given him; an inspector might say the match wasn't quite right; and both men could be correct!

The National Bureau of Standards entered into color research in 1913, at the request of the Department of Agriculture, which needed a legal, authoritative method of classifying butter and oleomargarine colors. Among those who then worked with color, the chief need was for a common language. Terms like "apple green," "purple," and "fire-

engine red" were not even good approximations of a language. If two men had to communicate, the only method which assured understanding was an actual swatch.

Bureau research helped to establish the first universal language of color, the system recommended by the International Commission on Illumination in 1931. This system, called the I.C.I. (or C.I.E. if you prefer the French title, Commission Internationale de l'Eclairage) is based on the fact that any color can be *matched*—not necessarily duplicated—by adding together the three primary colors in the proper proportions. For example, "kitchen red" viewed in daylight is specified as follows: $X = .15$, $Y = .077$, $Z = .011$.

Though the system provides a foundation for color classification, material samples of color are used in some industries. In the textile industry, for example, the accepted authority for color names is the Textile Color Card Association, which publishes a collection of more than two hundred color samples of pure-dye silk. All of these colors have been measured at the Bureau.

A recent color research project was undertaken for the Army Chemical Corps. Ground troops use color smoke signals, and the Chemical Corps has been trying to develop more vivid colors. The Army called on the Bureau for a means of color measurement which would tell the chemists when they were making progress, and which could also be used to test samples of smoke signals produced by suppliers.

Color research is a young science, and of the questions not yet answered many concern the nature of human vision. The Bureau of Standards isn't directly engaged in physiological or psychological research, but this is one of the meeting-grounds for scientists today.

For purposes of industrial process control, modern color standards are effective. Indeed, shortly before his resignation, former Bureau Director Condon said: "Conformity to a color requirement can now be determined with the same assurance as size, shape, or strength."

It may take years to develop a new national standard. There is no task calling for such infinite patience, skill, and precision as absolute measurement. Indeed, there can be nothing more precise than absolute measurement, for such measurements fix the limits of precision for all of the world's measurements.

The man who seeks accuracy to one part in a million may spend months, or even years, at his task. But when standards are used in manufacturing, measurements must be made quickly, at times instantaneously. These measurements must often be extremely accurate, often to one part in ten thousand. Further, the measuring device should be simple, for it may have to be used frequently, and by many different people.

Manufacturers of silverware need a quick, reliable way of measuring the thickness of plated coatings. "Thickness" is linear measure, but this kind of measurement is not easily made with a yardstick. Further, the manufacturer needs a nondestructive measuring method, determining thickness without penetrating the coating.

The answer is an electronic thickness gage, and the Bureau recently announced its development of three types of such gages. They can be used for all metallic coatings which differ from the basic metal in conductivity. Measurements are made simply, by placing a probe against the surface of the coating.

In making lenses and other devices of optical glass, one must know, with great precision, the index of refraction—the light-bending properties—of the glass being used. The old way of measuring refraction was laborious; the specimen had to be ground and polished.

The Bureau's new method, announced in September 1953, eliminates this work; the sample is simply cut with a 90-degree edge, and fitted into a hollow. A liquid makes contact between the sample and the hollow. If the cutting is accurate, the index of refraction can be measured in a few minutes with an accuracy of 2 parts in 100,000.

A more elaborate instrument is the N.B.S. Magnetic Compton Spectrometer, which makes accurate analyses of X-rays having energies between 0.2 and 12 million electron volts. One use of this instrument is in determining the shielding requirements around high-voltage equipment and nuclear reactors.

Of these Bureau-developed devices, many qualify as inventions, and they have been patented. Under United States law, patents have been granted in the names of the individual inventors, members of the Bureau's staff. Several hundred patents have been granted to Bureau employees. They receive no royalties. If an invention is made during working hours, or with Government facilities or information,

or if the invention is a "consequence" of the inventor's official duties, all rights in the patent belong to the Government.

Among the new standards which the Bureau has provided for industry are several hundred "yardsticks" of a new kind: not units of measurement but specimens of materials. These are standard samples of brass, steel, oil, copper and other materials, samples which the Bureau certifies as having a known, precisely-determined composition.

One of the steel samples, for example, will be used by a metallurgist in a steel mill. His task is to control the composition of the steel being manufactured. Periodically he takes samples from the mill production and runs analyses.

How can he be sure his analyses are correct? Any of a dozen things might go wrong, to influence his findings. The Bureau sample provides a simple way of checking. When he analyzes a mill sample, he *also* analyzes the Bureau sample, simultaneously, step by step, using identical procedures. Since the Bureau sample has a known composition, comparing his analysis with the certified analysis will reveal any errors in his procedure. If his analysis of the Bureau sample proves correct, then his analysis of the mill sample is verified.

The first standard samples were provided in 1906, as an aid to analytical chemistry. Today samples are certified by the Bureau not only for chemical composition, but also for density, melting point, viscosity, acidity, color, gloss, index of refraction, and heat of combustion. Recently radioactive samples have been added to the list: artificial radioisotopes for use in nuclear physics, biochemical research, and industrial research.

From electricity in the nineteenth century to nuclear physics in the twentieth, from the gasoline engine to the rocket motor—each new advance of science and industry brings needs for new standards and needs for new measuring instruments and devices.

Today, when metrologists meet, a chief topic of discussion is a change in the fundamental standards, the standards of mass, length, and time. From the very beginning, as we have seen, man has sought natural units of measure. Finding them unwieldy, he turned to arbitrary units. But science still seeks natural units. There are certain

risks in the use of arbitrary objects, even if they are safeguarded against loss or damage or deterioration. No physical object is invariant. Changes may be small and slow, even imperceptible, but they occur.

Today the search for natural units is approaching success. The national standardizing laboratories of the world are considering the possibility of natural atomic standards for the fundamental units of length, mass, and time. Indeed, as we have indicated in Chapter VIII, the Bureau already has an atomic clock in use.

A wavelength of light is likely to become the fundamental unit of length. The Ninth General Conference on Weights and Measures, held at Sèvres, France, in 1948, agreed on the principle, but the 33 nations represented there were not ready to decide what wavelength or how it should be done.

Each spectral line has an unvarying wavelength. The problem has been to obtain a line narrow enough to observe accurately. The green line of a mercury lamp has been used as a spectroscopic standard. But natural mercury is a mixture of seven isotopes, and its spectral line is complex.

By neutron bombardment of gold, Bureau researchers, at Oak Ridge, Tennessee, produced a single isotope of Mercury 198. Lamps made with this isotope yield a narrow line, well suited to measurement.

The German national laboratory favored an isotope of krypton for the standard, and the Soviet institute offered an isotope of cadmium. Representatives of eleven nations recently recommended that eventually the meter be defined in terms of the wavelength in vacuum of a line given by some isotope—which one they were not ready to agree—and that the value assigned to that wavelength be derived from the standard red cadmium as used in spectroscopy, without going back to the meter bar.

Scientifically the change is important, though when it is made there will be no noticeable effects. There are 1,831,249.21 wavelengths of Mercury 198 in an international meter. Should Mercury 198 become the fundamental standard, rather than a secondary standard as it is today, the relationship would remain unchanged, but the statement would be reversed: a meter would be defined as 1,831,249.21 wavelengths of Mercury 198.

The mercury-lamp standard is in unofficial use today. The National Bureau of Standards has supplied a number of these lamps to other laboratories, providing them with a measuring instrument more precise than any micrometer or gage.

While an atomic standard of mass is not yet at hand, we know that invariant units of mass exist in nature. All that is lacking now is a suitable method to adopt them as fundamental standards.

These are the latest installments in a long-continued story: to study the atom, new means of measurement were needed; and from the study of the atom are coming new standards and new instruments.

15

MACHINES WITH MEMORIES

ON ELECTION NIGHT, 1952, AN ELECTRONIC MACHINE NAMED UNIVAC was introduced to the television audience. News commentators explained that before the first returns arrived, technicians had fed into the Universal Automatic Computer—its full-dress title—a mass of information and certain instructions. As rapidly as precincts reported the votes for Stevenson and Eisenhower, the figures were given to UNIVAC for analysis.

A number of those who watched the broadcast thought the political experts somewhat patronizing and uneasy in their relations with the new electronic colleague. A few recalled that craftsmen, some years ago, occasionally tried to smash the machines which threatened to make hand work obsolete. But it wasn't long before the experts regained confidence. UNIVAC made up its mind and predicted an Eisenhower landslide. That, they thought, was absurd. It was much too early in the evening and only a scattering of returns had come in. UNIVAC's operators hastily made some adjustments.

Later, of course, UNIVAC was vindicated. But two years later UNIVAC floundered badly in predicting the results of Congressional elections. That year its showing was worse than that of the better-informed human analysts.

Though UNIVAC's public relations may have suffered because of this failure, the fact is that neither success nor failure in such an undertaking can be attributed to a machine. In both cases UNIVAC

did precisely what it was told to do by its operators. It had no information to work with other than what they provided, and it could evaluate that information only as they instructed.

The first of these limitations is almost absolute. No machine has yet been built which will gather any information other than that which its designers and operators intend. The second limitation is much less rigid. Given enough time and enough capacity, it is possible for an electronic machine to discover for itself, by experiment, what weight should be given to different kinds of information in predicting their combined effect.

No writer can report what the exact limits of machine performance are, because anything he writes will be out of date before it is set in type. No field of science and technology has evolved with such explosive speed as this one. Today the only visible delaying factor is manpower, engineers and technicians to build and operate the machines which have been designed. Indeed, the field has changed so quickly that terminology has not kept pace. These giant electronic machines are usually called "computers," though computation is only a part of what they do, and though some of them perform no arithmetic operations.

They have been called "giant brains," and some of their feats, as reported in the press, seem superhuman. Several of these machines have defeated all human opponents in games of skill and outguessed them in games of chance.

But "giant brains" they are not. True, their operations simulate, after a fashion, some of the operations of the human nervous system and brain. They can do some things much more rapidly than human beings can do those particular things. But the best of them is a clumsy toy by comparison with, let us say, the human eye.

It is just barely conceivable that some day an electronic machine might be built which rivals or exceeds the human machine. Machines have memories. They can accept information from the outside world, digest it, relate it to their memories, and reach conclusions. They will accept information in many forms: numerical, alphabetical, symbolic. Some will respond to devices which sense temperature, sound, light, moisture, pressure. These sensory facilities could be expanded and refined.

Further, the machines are not limited to giving responses in the form of information. They can also act. Computers are being used to inspect products, control industrial machinery, and perform other mechanical tasks. Computers have been designed which, on proper instructions, change their own circuits.

Even more fantastic things have been done and can be done. But to appreciate them is to learn a new appreciation for the human mechanism, which is far more compact, versatile, trouble-free, and in certain important respects much more simple and rapid in operation.

No one thinks less of man because he can lift a mere hundred pounds or so, while a machine can lift tons. Like hoists and derricks, electronic computers are extensions of man, built by him and responsive to his orders. But they are the most complex machines man has ever built, and with their aid he is likely to change the world in ways few people can now imagine.

Indeed, we have already passed the threshold into a new era, begun a second industrial revolution as portentous as the first. Perhaps the most striking fact is that this revolution would occur even if all research were halted today, if engineers merely applied what is now known. Far from being halted, research is moving ahead at an accelerating pace, testing a dozen new frontiers, surrounded by an atmosphere of excited and awed enthusiasm reminiscent of the Manhattan District and Los Alamos.

The general public hasn't seen much of the first big changes because all of the early computers were used chiefly for military purposes, doing work that was mostly secret. Further, some of the first machines were designed primarily to perform long and intricate mathematical calculations, impressive to the layman but unrelated to his own experience.

The first industrial installation of a big computer was made in 1954. A handful of orders were filled that year. By 1955 commercial production was gaining momentum and new companies were preparing to build computers. But full-scale production is still a few years away, even if manpower can be found to build, install, service and operate all of the computers commercial customers order.

The first business UNIVAC is saving its user, the General Electric plant at Louisville, Kentucky, about half a million dollars a year.

What it saves, mostly, is time, people's time. It is making up payrolls, controlling stock and inventory, handling production scheduling, calculating design data for the engineering department, and keeping financial records.

This is one phase of the new industrial revolution: a revolution in office methods. But it's only a phase.

Very broadly, computers fall into two general classes: digital and analog machines, and both have familiar forms. The Chinese abacus, beads on a string, is a kind of digital computer; and so are your ten fingers. A digital computer counts on its fingers. In an electronic computer fingers are represented by vacuum tubes, diodes, electrostatic charges, magnetic charges, and electrical pulses.

An analog computer represents variables by physical quantities or states. For example, temperature is a variable, and your household thermostat is an analog device, each temperature point being represented by degree of curvature of a bimetallic strip. The flyball governor on a steam engine is an analog device, the speed of a rotating shaft causing the flyballs to be pulled further from the shaft, actuating a valve to reduce the flow of steam and thus slow the shaft.

For the moment, let's consider the digital type of machine, which is new only in its electronic form. The abacus is centuries old. In 1642 a French mathematician, Blaise Pascal, built the first known mechanical calculator. A few years later Sir Samuel Morland designed a multiplying engine, but he couldn't build it. In 1834 Charles Babbage described automatic calculation in a remarkably modern manner, envisaging a machine fed by "punch cards" which would complete a series of operations automatically.

What limited these men, and others, was engineering. They understood the essential principles of automatic calculation. But in their times such machines couldn't be built for lack of materials, tools, and skills.

Mechanical desk calculators were introduced some years ago, first hand-cranked, later electrically driven. The first successful office machine to multiply and divide mechanically was built in Germany in 1891.

Desk calculators are finger-counters. Man has ten fingers, and,

years ago, when he ran out of fingers he made a mark, meaning 10, and began over. A desk calculator has gears with ten teeth. When a gear wheel moves ten positions, completing a revolution, it nudges the adjacent gear forward one space, like the odometer on your automobile instrument panel.

Mechanical calculators save time, but they perform only single operations. If a computation requires six steps of addition, multiplication, division and so on, the operator must set up the machine for each step, read the answer, clear the machine, and set up the next step.

Automatic computers, described by Babbage more than a century ago, are a long step beyond mechanical types, much further than, for example, an automatic washing machine is beyond a manually controlled machine. The automatic washing machine performs a series of operations in a prescribed sequence. An automatic calculator must be able to record the partial answers of intermediate steps, store them away, then call them forth and use them in later operations.

Some interesting machines called "differential analyzers" were built in the 1920's. Lord Kelvin invented such a machine (on paper) in the 1880's, but like Babbage's calculator it was never built. Oddly enough, Kelvin's writings on his machine were rediscovered some time after the first actual machines were built at the Massachusetts Institute of Technology under the direction of Vannevar Bush.

In 1937 work began on the first of the successful automatic computing machines. This was Mark I, built at Harvard University, sponsored jointly by Harvard and International Business Machines. Mark I, still in use today, is a relay computer. In place of toothed gear wheels, its "digits" are electrical relays; numbers are represented by combinations of the "on" and "off" positions of a number of relays. Bell Laboratories built several relay computers, and others were being built when the first all-electronic machine made them obsolete. This was ENIAC, the Electronic Numerical Integrator and Calculator, built at the University of Pennsylvania for the Army's Aberdeen Proving Ground. It began operating in 1945.

An all-mechanical automatic computer, were one built to rival present-day machines in capacity, would be huge, cumbersome, noisy, unreliable and slow. Mechanical motion, provided by motors and transmitted by shafts and gears, would have to be slow because of the

stresses imposed by starting, stopping, reversing, and gear-changing.

Electrical relays are faster. A pulse of electricity energizes a magnetic coil, which acts on a delicately-poised rod, causing it to close an electrical contact. A relay can switch from "on" to "off" in 1/100th of a second. The motion of the rod is mechanical, but other operations are all electrical.

An electronic computer has no moving parts. Its components are vacuum tubes, germanium diodes, condensers, electrostatic devices and the like. Such components can switch from "on" to "off" states in as little as 1/1,000,000th of a second!

Thus an electronic computer can multiply two ten-digit numbers in the blink of an eye. But such speed, while remarkable, would have little practical value if, as in a desk calculator, each step in the calculation had to be set up by an operator.

Suppose you wished to know the square footage of all surfaces in a room. You would add length and width, multiply by two, and multiply by height—three steps. Setting the answer aside, you would calculate window and door areas and add them together. Retrieving the earlier answer, you would subtract the last.

On a desk calculator, each step would be a distinct operation. A modern electronic computer would accept all of your measurements and your instructions at once, perform the sequence of calculations, and deliver only the final answer.

ENIAC was designed to perform far longer series of computations automatically, such as those required to plot the trajectory of a shell. By hand methods, such a series took hours. ENIAC can do it in less time than the shell takes to hit its mark.

The day ENIAC made its first public appearance was, in a way, more significant than the day the first atom bomb exploded. In peacetime, computers will probably influence human affairs more profoundly than atomic energy. Yet most newspapers ignored the story; most of those who reported it did so briefly and without comment. They missed the key fact: ENIAC was not merely rapid; it was a machine with a memory.

Memory is the key to understanding the modern electronic computers. The idea of machine memory was not precisely new. Punched

cards were used more than a century ago to control Jacquard looms, and Babbage's design called for similar punched cards. Indeed, it was the punched-card memory that initiated the chain of events in the United States which, in due course, led to ENIAC. Like many developments in science, it was not an idea conceived purposelessly, but as an answer to a pressing problem.

It began with the United States Census about 1880. The earlier national censuses had been elementary affairs, the first of them counting only four million people. But after 1850 there were more people and more information about them was gathered. By 1880 Census officials faced the alarming fact that an army of clerks might not finish tabulating the returns before the 1890 Census began!

Dr. Herman Hollerith, statistician, was hired to look into methods of more rapid tabulation, and under his direction a unit-card system took form, not unlike the Jacquard cards. Census information was reduced to code, represented by combinations of punched holes. For example, a hole in a certain position meant "farmer." A combination of two holes in specific positions represented a person's age. Machines were designed which could read these holes, sorting into stacks cards carrying identical combinations.

Hollerith and James Powers, also employed by the Census Bureau, ultimately left to set up companies manufacturing punched-card equipment. Today such punching and sorting apparatus is used by the Census and by many business firms.

Punched-card sorters don't perform computations (though types are made today which have computing facilities added). Stacks of cards are fed into the machine and sorted into compartments, counters registering the number dropping into each compartment. When such equipment is used, desk calculators are required to calculate averages and percentages.

The 1880 crisis was averted. But another threatened just a few years ago. Modern punched-card machines can sort up to 600 cards per minute. But the mass of data gathered in a modern Census is so vast that hundreds of such sorters, plus desk calculators, plus thousands of clerks, aren't equal to the task of compiling Census tables. In 1940 the United States Census was again bogging down.

J. W. Mauchly and J. P. Eckert, Jr., engineers in the ENIAC de-

velopment, began discussing a bold idea with Census officials. Not much could be done until ENIAC was completed and operating. But then Mauchly and Eckert formed their own corporation, told the Census Bureau what they could do, and got a contract to design and build a new type of electronic computer.

By now the National Bureau of Standards was in the picture. Bureau men had kept up with computer development (because guided missiles and proximity fuzes employ computer principles) and, since both Census and the Bureau are Department of Commerce agencies, the Bureau was asked for advice. The Bureau was given the task of administering the Eckert-Mauchly contract.

One significant difference between ENIAC and the new machine was the use of binary arithmetic in the latter, while ENIAC circuits were arranged decimally, ten pairs of tubes in rings corresponding to the ten teeth of a gear wheel or ten fingers.

But men have ten fingers, while electronic devices have only two, called "on" and "off." Machine design could be simplified by designing a system of arithmetic based on two digits.

In binary arithmetic, 1 is written as *1*, 2 is *10*, 3 is *11*, 4 is *100*, 5 is *101*, 6 is *110*, 7 is *111*, 32 is *100000*. It seems cumbersome, but people who use computers needn't translate from decimal to binary numbers. It can be done automatically, and in machine operations the binary operation is far simpler. In ENIAC, twenty pairs of tubes are needed to represent the two-digit number 32. In binary code six are sufficient.

The binary system is by no means alien to human beings, for it is strikingly similar to the operations of the human nervous mechanism. Signals traveling over human nerves are trains of pulses which do not vary in intensity. A stronger stimulus produces more pulses, not stronger pulses. Through the circuits of a computer, trains of pulses also travel, pulse and no-pulse corresponding to on and off.

Almost any kind of information can be represented in binary code. Braille is one way of putting the alphabet into binary code, dot and no-dot.

The Eckert-Mauchly machine would have memory enough to hold, internally, 84,000 "bits"—binary digits—stored in a novel device: tanks of mercury. Trains of electrical impulses would be converted to slower

sound waves, traveling the length of a tank. At the opposite end they would be changed back into electrical impulses and fed into the tank again, thus cycling and re-cycling until needed.

Internal memory could have been provided by vacuum tubes, but the number of tubes would be enormous. To enlarge memory capacity within reasonable limits of expense, space, and circuitry means some compromises with speed; the essential fact is that internal memory is automatic, and it can be drawn upon when needed without human intervention.

By the time the Eckert-Mauchly design was ready for approval, other government agencies were interested, and the Bureau was asked to manage contracts for three more machines.

None of this was plain sailing, and many engineers were frankly sceptical. It was far from certain that such intricate devices with so many components could be operated successfully. They might break down so often as to make them impractical. Further, so many untested ideas were being tossed around that freezing a design was hazardous.

Bureau men quickly decided that the necessary research couldn't be done on paper. They needed real equipment, and the Air Force needed a computer to experiment with problems in military management. So it was agreed in 1948 that an "interim computer" would be built at the Bureau, financed by the Air Force.

It began as a rather small design, though based on new principles, different from the machines being built under contract. It was elaborated on from time to time, growing to quite respectable size in the end, but even so it was ready for productive operations in twenty months, a full year before the Census machine was ready for tests. The men who did it brush off this comparison as unfair. Since the Standards Eastern Automatic Computer was to be used in the laboratory, it could be a "bread-board" affair, while the contract machines were prototypes of commercial models, with more severe assembly requirements.

When SEAC was completed in May 1950, it was the fastest and most versatile computer on earth, and it has been improved since. It has 64 mercury tanks for internal memory, plus 45 Williams electrostatic tubes, cathode ray tubes, resembling the picture tube of a television set, on which binary digits are "memorized" as small bright

spots. A new design feature was use of vacuum tubes for power amplification only; germanium diodes, smaller and more durable than vacuum tubes, were used for all computing and switching.

The Census machine was completed by Eckert-Mauchly, now a division of Remington-Rand, in 1951. This was the first UNIVAC, and UNIVAC was the first big electronic computer to go into commercial production as a stock model.

What's a big computer good for?

In a trial run, SEAC automatically divided a given number by 80,000 trial divisors, which it selected in accordance with brief instructions, in a half-hour. To which most laymen might reasonably respond: So what? In science and engineering such mammoth problems often occur. Indeed, some scientific and engineering problems were never attacked prior to the advent of computers because of the staggering manpower requirements. But, in everyday business affairs, how often do such problems occur?

We are just beginning to find out. Weather forecasting is a good example. Many people know that in addition to a few hundred professionally-manned weather observatories in the United States there are several thousand observation points where daily readings are made by volunteer observers. What many *don't* know is that many of the data accumulated are not used in daily forecasting; they are gathered simply for the permanent weather history.

Weathermen have long believed that they could improve the accuracy and extend the range of their forecasting if they could process a larger mass of data. But if they tried to do this by manual means, the "forecast" wouldn't be ready until days or weeks after the event! With computers available, weathermen are getting their first chance to see what they can do.

Careful studies of past floods along the Ohio River have given experts a sound basis for predicting flood conditions. Once again, with their former tools they could not process the data in time for the results to be of any use. Now a computer is being used to make predictions.

Such big problems exist in many fields. But there are other computer applications which are simpler and more familiar, in almost any large office operation. They don't look like big problems, because each

of the clerks employed is performing a fairly simple task, using an adding machine, desk calculator or bookkeeping machine. No individual calculation presents any difficulty. But the task is in reality a large one, broken down into a number of small pieces. A computer wouldn't aid an individual clerk—but it might replace a roomful of clerks.

Consider the matter of making up a factory payroll in a plant which has a piecework system. The clerk begins with the records of pieces produced by each man each day, looks up the rate on each piece, and calculates the men's base earnings. A worker may have had an hour of idle time on Tuesday which is to be paid at day rate for his labor grade. On another day he had two hours of time when his machine was not operating properly; this is to be paid at average piecework earnings for the previous pay period. Then the union contract calls for addition of 5¢ flat per hour worked—his regular work week minus two hours in which he was absent. This particular man was involved in a union grievance several months before; an arbitrator has just ruled in his favor, so now a differential must be calculated from the old records and added to this week's check. Now come deductions: social security on the first $4,200 of earnings; federal and state income tax withholdings, welfare fund, union dues, defense bonds, perhaps other items.

The clerk has many calculations to make on each man's pay; further, the clerk must look up many facts before calculating.

If a computer is installed to make up the payroll, the clerk need do no more than code the *new* facts and give them to the machine. Everything else is in the machine's memory, including full instructions on how to do the computing. Given the new facts, the computer will take only a few seconds to calculate the week's pay, print the paycheck, add the new facts to its memory and to the company's financial records.

Of even greater interest to management is the fact that the machine can be instructed to make up summaries of stored facts in any desired combination and arrangement. With a computer, operating summaries can be obtained in an hour or two, instead of two weeks late.

In a computer used primarily for calculating, memory is an indispensable auxiliary function. Masses of data can be stored internally

and externally for permanent reference or for purposes of handling a series of problems. New data developed by calculating can be added to the memory automatically. The memory function is what gives machines their ability to teach themselves, and machines are some times used to play games, not for the amusement of their operators, but to experiment with such functions as learning.

If a machine were being set up to play tic-tac-toe, it could be given complete instructions: what to do to counter any move the opponent might make. But the number of possible combinations in chess is so large that providing such specific instructions would be impractical. So a chess-playing machine would teach itself, by trial and error. It would make its initial moves in accordance with the rules, which would be in its instructions, but at random. Playing against a human opponent, it would lose all or nearly all of its early games.

But the machine would never make the same mistake twice! If move *x* in situation *Y* led to an unsuccessful result, the machine would try something else the next time situation *Y* arose. Good and bad results would be stored in the memory, and as the memory grew the machine's chess-playing would improve, until in time it would win nearly all of its games against any opposition.

Of course it would take a very long time for a person to play enough games with the machine to develop its memory sufficiently. So, instead of this, the computer would compete with another computer, or perhaps even with itself. Under these circumstances thousands of games could be played in a few minutes, and in a single day the machine would have acquired far more experience than the oldest living chessmaster.

In practical affairs, the significance of this kind of operation is to maximize what machines can do with a minimum of instructions. In early computer designs, setting up the problem for the machine took many man-hours, often far longer than the machine needed to solve the problem, and squads of highly skilled mathematicians were needed to keep one machine reasonably busy. Much has been done since to shift the work load from men to machine. In a payroll operation it is now possible to give the machine sets of instructions, one of which might be called Operation A. Though the computer may be used for

numerous other operations, a single brief instruction will cause it to set itself up for Operation A.

It is at this point that the term "computer" begins to be inadequate. It fits rather neatly when describing machines performing mathematical calculations. But the machines are equally impressive timesavers in processing information, sorting and assembling data, combining it in different ways, putting it in any desired form. Internally, the difference isn't as marked; it is most apparent when looking at the information fed into the machine and the replies coming from the machine.

Today one of the frontiers is expanding memory capacities and speed of access. Many new memory devices have been introduced: magnetic drums, electrostatic devices, and most recently tiny magnetic rings. But though memories are being made larger, a computer's internal memory has fixed limits.

There is no such limit on external memory: information stored in a form which can be read by the machine's input. Such storage is in the form of punched cards, rolls of magnetic tape, reels of film, spools of magnetic wire, punched tape—all in binary code.

In these forms information can be stored compactly. Indeed, the potential compression is surprising. One authority suggests the possibility of storing twenty million readable marks on one square inch of fine-grain film! That's still far out of reach, for there is no apparatus capable of making or reading such marks accurately. But it is quite possible today to store 1,400,000 typewriter characters on a narrow spool of tape seven inches in diameter.

External memory is somewhat less available than internal. If a collection of several thousand spools, reels, or card file drawers accumulates, some person must select those which are presented to the machine and place them in position. The time required to locate a set of data in this way is longer than that required to search internal memory.

But the distinction between external and internal is rapidly breaking down, as devices are designed which refer to files automatically, choosing the right files and bringing them into reading position.

Memory is a tricky business, however, the term covering many

different kinds of operations, some rather mysterious. Storing information is easy. A business firm could store all of its records by tossing them into a coal bin, helter-skelter. The problem is locating what is needed, at the right time, without waste motion.

The human memory is remarkably superior to that of any computer yet conceived. The brain's input is like the coal bin, facts being tossed in helter-skelter. Yet a needed fact is often available instantly, without conscious reference to any index system. Indeed, a fact may have been stored away years ago, the person never realizing it was stored, never aware of it in storage; yet it bobs to the surface at an appropriate time.

Computers have different methods of searching their memories, yet each must follow a pattern, and in many cases thousands or even hundreds of thousands of items must be inspected to locate one. Only high speed makes some of these searches practical.

Someone has estimated that if the entire contents of the seven million books in the Library of Congress were recorded in binary code, one UNIVAC could search the entire collection in twenty hours. Sounds remarkable, doesn't it? No human being could read through so many volumes in twenty hours or twenty years.

But what would be the purpose of such a search? If, for some odd reason, you wanted to know exactly how many times the word "anaphylaxis" appeared in the seven million volumes, UNIVAC would be the best way of getting the answer. But what if you wanted to know Napoleon's birth date? You could find it quicker without UNIVAC.

One of the librarians could do it in less than two minutes, walking a few steps to a shelf, taking down a dictionary of biography, and turning to the right page. You might have to use the card file to perform the step the librarian performed mentally: locating the right volume.

The fact is that the Library is searched about five thousand times each day by people who use memory, judgment, card catalog, bibliographies, volume indexes and other selection methods. Such searches, narrowing down to the objective by a series of steps, are much more rapid than searching the entire collection, item by item, even if such straight-line searching is done electronically.

This doesn't rule out the possibilities of electronic searching; it

merely demonstrates that speed alone isn't enough. Computer memories are becoming more versatile. New ways are being developed to organize, store, and search for information. For some kinds of searching, at least, machine methods will eventually exceed and supplant the present systems of libraries and office files.

In government and business some of the most time-consuming tasks involve no computation whatever, merely a searching for and rearrangement of information. Some idea of what can be done by machines to eliminate human labor in such tasks is given by a computer called the Rapid Selector.

This is a pure memory machine, and its memory is external, except for instructions given to it at the beginning of each problem. It stores whole pages of information, uncoded, as photographic images, much reduced, on a strip of film. Beside each frame on the film a brief description of the contents of the page is given in binary code, black dots. A reel of film stores 72,000 pages; 24 reels can be stored in a space the size of a filing cabinet.

When a search is to be made, instructions are given to the machine. It scans a 72,000-page reel in about three minutes, scanning each coded abstract and comparing it with its instructions. When it finds a match, the machine makes a photographic copy of the entire page, without stopping.

Ralph Shaw, one of the men who helped develop the Rapid Selector, explains how it might be used for business correspondence:

> "Assuming a file of one hundred thousand letters, which is a large file, and assuming that each letter is indexed under six entries, the machine would have to search six hundred thousand entries to locate any letter, or all letters on a given subject or on a given area. The machine's searching time, even if the whole file is searched, including time of reproduction of the letter or letters sought, should be only about five minutes. Regardless of the number of file clerks, typists and photostat operators employed, it would not appear feasible by normal means to pull, on order, letters on any one subject from the files and to make copies of them in anything approximating this period."

It's too soon to tell whether this is the direction of the future business office because new developments are opening other possible ways. For example, S. N. Alexander, head of the National Bureau of Standards computer laboratory, suggests magnetic recording would make files fully automatic. There would be no photographic print of a stored letter. The person wanting the information could be miles away, dial for the information, and have it delivered automatically to his desk-side printer.

This solution seems more probable for office work because it would facilitate an even more radical step. With such a system, why make a typewritten letter in the first place? Instead of printed letters, the keyboard operated by a secretary could code magnetic impulses, and a computer could automatically transmit the message to the addressee's printer, insert the information in both sender's and addressee's automatic files, and give a confirming copy to the sender.

Some engineers think it may be possible to eliminate the keyboard, so that human speech would be interpreted electronically into written words. This sounds fantastic, yet present-day computers are performing equally prodigious tasks.

The Bureau's SEAC, for example, is saving money by analyzing bids. It sounds simple enough, just to find the lowest bid on a government procurement invitation; but the procedure is actually quite involved. A large purchase may call for delivery of different portions of the total to many different addresses; unit prices are F.O.B.; so the firm whose unit price is lowest may be so distant from some delivery points that the government's total cost would be higher than buying from another bidder. Often a purchase may be spread among a number of bidders. What's the best combination? SEAC answers in a few minutes.

The Air Force has a staggeringly intricate supply problem. The supply needs of a given air base this month may be irrelevant to its needs next month. Planes of a new type may be assigned to the base, and if they are to be serviced the right quantities of thousands of parts must be on hand when they arrive. Scramble together the number of planes in service, the number, sizes and characteristics of bases, the huge variety of parts and supplies, the complexities of manufacturing, packing, warehousing and distribution, among other factors, plus the

need for precision timing, and you may have a faint idea of a problem a computer is now managing quite nicely.

What kind of computer is most familiar to the average man? Answer: a telephone exchange. This isn't a play on words or a stretching of fact; an automatic dial exchange is a full-fledged electronic computer, more complex than most because of the huge number of inputs. The dial on your telephone is an input device. Telephone exchanges are becoming more complex, more fully automatic. Extended range dialing is used in many cities now. Long-distance dialing is operating in a few places. In and near Philadelphia, three test installations are demonstrating how far automation can go today. In these exchanges, automatic equipment records calls made by subscribers, adds overtime and toll charges, makes up monthly bills, including taxes, prints the bills, inserts them in envelopes, applies postage—all without human intervention.

Ten years ago, when the first electronic computer was being tried out, only a rash visionary or a writer of science fiction would have predicted what has now become accomplished fact. Some writers, then and even more recently, doubted whether the computers would really work.

It was believed then that the life of a vacuum tube is about a thousand hours. Since ENIAC had eighteen thousand tubes, eighteen failures per hour might be anticipated, each introducing the possibility of error. Circuits might be designed to check for tube failures, but since these added circuits would contain added tubes, the probability of failure would be even greater. It turns out that tubes last much longer than a thousand hours, more than 8,000 hours in some installations, and the use of diodes and transistors will reduce failure possibilities even more.

A few years ago experts were saying that input speed seriously limited the big computers. Once information had been fed in, it could be manipulated electronically, at electronic speeds. But every input device is mechanical, requiring handling of physical objects such as cards or tape. Mechanical speeds are necessarily much slower than electronic. A punched card, should it be moved past a reader at the maximum speed of electronic scanning, would be moving fast enough to pierce several inches of armor plate.

Recently however, new input methods and devices have been devised, and input speed is no longer the problem it once seemed to be. Nor is external memory.

The Bureau's SEAC is now equipped with several magnetic-tape memory units, "external" but computer-controlled. A loop of tape rests lightly on rollers, which are driven continuously. When information from a unit is required, a magnetically operated jam roller engages the tape against one of the large rollers, quickly starting it in motion. The tape falls into loose folds in a narrow glass tank, piling up for easy access. Several thousand feet of tape can be stored in one unit. Of course, the longer the tape the longer the access time. Normally the loop is about twelve hundred feet long, storing up to four million binary digits, and average access time is under four minutes.

Both storage capacity and access time can be improved still further, and will be. A number of tapes, or a number of channels on different tapes, can be scanned simultaneously. Selection systems, corresponding to the selection steps in using a library, will eliminate much scanning.

In using a modern computer, the most laborious task is preparing information for the input. In preparing information from a questionnaire survey, for example, the first step is coding: clerks review the questionnaire and turn the responses into numerical or alphabetical code. Other clerks then punch this code into cards, or prepare tapes. One of the more dazzling probabilities of the future is that ways will be developed not merely to short-cut these steps but to eliminate much of the human labor now expended in gathering the information. Extensions of computers may be devised, automatic observers, able to gather information about the world and record it automatically!

Weather forecasters use information gathered by instruments. Some of these instruments are sent aloft by balloons equipped with telemeters. Information on temperature, humidity, and barometric pressure is broadcast from the balloons in code. Ground observers translate this information, retranslate it into another code and transmit it by teletype to the forecasting center. Here the receiving instrument again translates the code impulses, and weather personnel retranslate it into symbols on maps.

There is no theoretical reason why most of these steps can't be

eliminated. Some day the whole circuit may be automatic, from the sensing instruments in high-flying balloons to central computers which receive information and translate it into weather maps.

Human beings have a variety of "inputs" in their senses of sight, smell, taste, hearing, temperature-sensitivity, weight-sensitivity, pain-sensitivity and so on. The sensory apparatus with which a computer might be provided could be far more elaborate and versatile. Any kind of sensing device could be used, providing the computer with accurate information on wind speed, humidity, precipitation, or, in a factory, thickness, surface roughness, density, tensile strength, acidity, and any of hundreds of other qualities.

Further, the kinds of outputs can be as varied as the inputs. Computers can produce processed information. They can also be used to control devices which turn switches, adjust valves, regulate machine speeds, reject imperfect items. They can, in fact, control almost anything which human operators control, and do it quicker, more accurately and more dependably.

Let's take a look ahead at a society in which computers have taken over many routine functions. For this immediate purpose, let's leave aside the automation of factories and see what may be done for us—and to us—by information processing.

There is one new idea in this forecast, which may seem revolutionary but is well within the range of present-day technology: interconnection of computers. If a computer can control a machine, it can also control another computer. It can *exchange information* with another computer. And it can do so automatically.

In this future day, you carry in your pocket a small metal or plastic plate. This is your identification card, your introduction to any computer you happen to meet.

This morning you buy a ten-dollar hat at your department store. The clerk tears a bit of tape from the hat and slips it, together with your plate, into what used to be the cash register.

The big computer downstairs goes into action. The hat is deducted from inventory, and a buyer is notified if stock is low. The clerk's commission is figured and stored away for the payroll operation at week's end. The computer checks your credit with another computer

at the credit bureau, obtains the name of your bank, and arranges with the bank's computer to transfer ten dollars from your account to the store's account.

You seldom have to write a check, and you seldom need cash. Slipping your plate into a slot at any store, restaurant, or ticket office makes the purchase and transfers the money automatically. If you travel on expense account, you carry a second plate, which will charge to your employer's account *only* the kind of expenses he authorizes.

How to place or receive a telephone call? Just slip your plate into any convenient telephone instrument. Calls are charged to your account. Anyone dialing your number will reach you, and you'll be notified of calls placed while you are away from an instrument.

Applying for a new job? You fill out no application form, submit no references. Borrowing your plate for a few seconds, the personnel office accumulates, from far and wide, as much of your personal history as it wishes, the records of any computer with which you have ever dealt.

As the memories of computers grow, many operations now classified as research will become mere button-pushing. Census-takers won't ring your doorbell to ask questions; all they need to know is in the memory banks. Chemists will search scientific literature electronically. You won't have a chance to chisel on your income tax.

In a way, this vision has enormous appeal, for our society is staggering under a mounting load of clerical work. Since 1920 the number of clerical workers has increased three times as rapidly as the number of industrial workers. Productivity per industrial worker has tripled. The increase in clerical work is largely unproductive, however necessary it may be.

The volume of paper records is no longer manageable. Warehouses are piled high with them, and the cost of maintaining these old files, the memory of our civilization, is fantastic. Society as a whole now faces the problem the Census once faced: the burden can no longer be carried.

The rapid expansion of human knowledge has led to decreasing effectiveness in using it. It is becoming more and more difficult for a research scientist to avoid duplicating work done in the past. Literature

searches are becoming more costly and time-consuming. In virtually any industrial plant in the United States one can find examples of obsolete practices still in use because no one has had the time or the means to learn of better ways tried and proved elsewhere. Business executives complain that they can't read more than a small fraction of the current literature relating to their business interests, much less dig into past records.

Indeed, while every business firm is severely limited in its ability to locate and assemble potentially useful information from outside sources, large corporations are also notoriously inefficient in making use of internal information. Swamped in paperwork, many executives find they can keep operating only by resorting to verbal transactions, exchanging information and instructions which are never permanently recorded. The case-books of management consultants are thick with examples of the consequent absurdities.

But the office revolution is in the making. A dozen different devices of the computer family are in use or nearly ready for trial, and others are on the drawing boards. Within a generation, much of the dreariest, most routine work will be turned over to machines.

Side by side with the office revolution, factory automation is making great changes in American manufacturing. There are in operation today a number of fully automatic factories, where men are needed for little more than giving the machines instructions and keeping them in repair. There are many more cases of automation replacing 50 workers with automatic devices tended by four or five watchers. Walter Reuther of the United Automobile Workers, C.I.O., says that automation may well slash the manpower requirements of the automobile industry from more than a million to less than two hundred thousand.

Will computers mean mass unemployment? It is easy enough to scoff at the idea, and history is on the side of the scoffers. The same fears were expressed in the early days of mass production and labor-saving machinery. But precedent is not necessarily proof, and the difficulty of saying anything that makes sense today is that no one knows, even within rough limits, what's going to happen and how fast. No one can predict how many computers will be in use even five years from now, and what they'll be doing, and with what results.

This is a revolution, the most rapid fundamental technical change

the world has yet seen. The vision of the future is perhaps even more frightening because of certain other powers inherent in computer methods. Like atomic energy, they can be used for man's benefit or contribute to his destruction.

Science-fiction writers have portrayed the mechanized society as wholly regimented and standardized. Some of the men who best know what computers can do are equally pessimistic and with better reason. Most of us are uneasy about invasions of privacy: wire-tapping, interception of mail, questioning of neighbors, and other techniques of the investigator. We are made uncomfortable by the knowledge that our dossiers are kept in official and semi-official places, where information, accurate or otherwise, is accumulated.

Computers could well be used as super-investigators, keeping on tap a permanent record of almost anything we say or do within the field of perception of any computer or its auxiliaries. From schools, courts, license bureaus, credit agencies, employers, hotels, department stores, bureaus of taxation, newspapers, organization files, voting lists, and hundreds of other sources, a dossier could be compiled by pushing a few buttons.

This won't happen in five years, though some of the essential pieces of the picture are rapidly becoming quite real. It may never happen, but it could. Of course the machines won't be to blame.

Of themselves the computers will do only what they're told to do. The point is, however, that they are enormously powerful information processors. Like all instruments of power, how they are used depends on what social controls are applied. Thus far man's record of devising and using social controls of such magnitude is rather spotty.

This is not a forecast of either doom or glory. But, for better or for worse, computers will have a tremendous impact on our world, and much sooner than most people realize. Until now most computers have been one-of-a-kind, costly experiments. Now commercial production is beginning. Standard models are on sale. Prices are coming down, and orders are piling up.

The beginning of commercial production is changing the role of the National Bureau of Standards. Bureau men have built three major computers contributing many new ideas in design and equipment; and they participated in developing several commercially built machines.

But the Bureau's staff is small, in relation to the engineering organizations of the major companies entering the computer race. And it isn't the Bureau's job to do what private companies are doing quite capably.

What private companies can do is shaped by their markets. Today their emphasis must be on standard production models which can be factory-produced. With a growing, almost untouched market for machines, their interest in building big one-of-a-kind computers for special purposes is dwindling.

There will still be need for unique machines, however, especially in government operations. The Census Bureau and Social Security Administration have clerical problems far exceeding those of the largest private insurance company. The Patent Office is falling further and further behind in its work, and a committee has been studying how a unique kind of computer might pick up the load.

Though the policy decisions haven't been made, it would be logical for the Bureau to become the Federal Government's computer center, consulting, designing and developing new types of equipment and circuitry. An example of what can be done is FOSDIC (Film Optical Sensing Device for Input to Computers), a Bureau development, which will scan pencil-marked Census schedules and convert them into machine language, eliminating the tedious and costly clerical work of encoding.

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UNIFORM, PERMANENT, UNIVERSAL

Now, AT THE END, THE READER MAY FEEL THAT HE HAS BEEN LED UP the garden path, diverted from a question in which he has a personal stake. What about the "great Deceit of all the Commons"? What about short weight? This science business is very good, but what's going on at the grocery?

The worst that can be said is that some places in the United States have weights and measures regulation not much better than in medieval England. But even there the consumer has decided advantages over what used to be.

The best of these is that standards are now fixed and universally available. Every state and many cities have sets of standards of measurement, reliably based on the national standards. There is no lack of opportunity for anyone to have a scale or a measuring tape or a volumetric measure checked against a reliable standard.

The fundamental standards are national, but Congress has generally left enforcement to the states. What's going on at the grocery store is a state and local responsibility, with occasional assistance from federal enforcement agencies.

The Food, Drug and Cosmetic act, for example, requires truthful labeling of packages, and a packer whose containers hold less than the marked amount can be charged with misbranding. The Department of Agriculture administers the Packers and Stockyards act; and

there are a Standard Barrel act and a Standard Container act which have helped to eliminate the numerous "quart" berry boxes which once were common.

But the agencies administering these federal laws have much more to do than watch out for short weight, and they don't have enough inspectors for a thorough policing job. Short-weight cases usually are incidental to their other concerns, unless there is a complaint. The best state and municipal laws are far more comprehensive than anything Congress has enacted, and it is only the states and cities that have enforcement organizations devoted primarily to weights and measures.

This is the pattern fixed in colonial days, and after the Revolution some states merely carried over their colonial statutes, most of them patterned after unsuccessful English models. There were numerous weaknesses and diversities, and some states, after initial experiments had failed, abandoned enforcement altogether. For more than a century, the American consumer had sporadic protection at best, and often none at all.

The reform movement which began at the beginning of the twentieth century might have made matters worse, if possible, had it not been for the National Bureau of Standards. The Bureau has never had police powers and wants none; but, as in the case of safety codes, it can and does suggest standard practices for others to adopt if they choose.

Soon after it was organized, the Bureau made a spot survey of local weights and measures administration, and the facts discovered, at the grocery store, were as bad as even the pessimists would have expected. So, in 1905, the Bureau invited local officials to attend a conference in Washington. Seven states sent representatives, and one of their first decisions was to begin work on drafting a model law. By the time it was ready seven more states were participating.

The conferences became annual events, interrupted only by World War II. The model law, with amendments to bring it up to date, has been adopted by most state legislatures. Through the conferences, now much better attended, enforcement people swap information and decide how to handle the new problems which arise.

But if you happen to live in Arkansas, Delaware, Mississippi, or New Mexico, your state doesn't have such a model law. Colorado

adopted one in 1955. Kentucky has had state regulation only since 1950. Maryland adopted a modern law but hasn't provided for adequate enforcement.

Who administers the law differs from state to state. In some states, actual enforcement is left to municipal authorities. Some have state inspection staffs. Others combine the two; the cities or counties have their own inspectors, and state inspectors plug the gaps.

The quality of inspection ranges from good to bad, though it's getting better. There was a time when weights and measures jobs were patronage appointments, handed out to the party hacks, who weren't expected to do much work. Today, in well-governed states and cities, inspectors are civil service appointees.

Changes in distribution and marketing have made drastic changes in their work. When Allen W. Corwin of Wellsville, New York, was appointed county sealer of Alleghany County in 1910, there were only two miles of paved road in his entire district. Most commodities were sold in bulk then: coffee, sugar, tea, crackers, lard, butter, pickles, rice. They were scooped from bins and barrels, and weighed on the scales to the customer's order.

Selling dry commodities by liquid measure was common then, Corwin recalls. Most merchants sold by gross weight, charging the customer for the weight of the container. About half the liquid measures he checked were short. Some computing scales had been sold to merchants with the guarantee that they'd cheat the customer. Three fourths of the wagon scales, tested for the first time, proved to be not even approximately correct. Even druggists' scales were inaccurate. Surveyors' chains erred by as much as six inches in 100 feet.

Corwin found then what hundreds of inspectors have discovered since. "At first there was considerable prejudice against my work, and insults were not uncommon." But resistance lessened when he showed merchants that they were often, inadvertently, short-weighting themselves, using scales that erred in the customers' favor.

In 1910, almost everything was sold by the merchants' scales and dry measures. Today nearly all dry commodities are prepackaged in weight-marked containers. Liquids and wet-packed items are also in sealed containers, marked with their weight or volume. Dry measures

have virtually disappeared from retail stores, and the scales are used only in the meat and vegetable departments.

Of course, every market does have its scales. How far can they be trusted?

In states and cities with modern weights and measures inspection bureaus, there is less than one chance in ten that a scale will be in error by more than a quarter-ounce per pound. If there is any error, it will probably be small, and the chances are about even that the error will be in the customer's favor. If a modern computing scale isn't serviced and adjusted periodically, it is more likely to be slow than fast. In a community where inspection is lax, the chances of error are much greater: about one in three. The margin of error will be larger, and a majority of errors will be in the merchant's favor. How much of this is deliberate few experts are prepared to say. Some of it is tampering, no doubt. It is probably true, too, that a faulty scale is more likely to be noticed and adjusted if its error penalizes the merchant rather than the customer.

Where there is regular inspection, deliberate tampering with scales is rare. This is not altogether because of fear of prosecution, for even in such cities an inspector won't come in more than a couple of times a year, and prosecutions are infrequent. When an inspector condemns a scale for repair, he doesn't, as a rule, bring action against its owner. Prosecution is usually reserved for gross and habitual violators.

Only a stupid and greedy man would set his scales to short-weight his customers by a large amount, such as two or three ounces in a pound. A sophisticated operator makes only a small adjustment, perhaps half an ounce per pound, well within the range of possible errors, unlikely to be detected by the customer, yet quite profitable in the long run, enough to more than double his net profits.

To what extent is this done? No one knows, for no comprehensive studies have been made in recent years; but men who know the field say that deliberate short-weighting is much less common than in the past. One reason is that so few sales are made by the retailer's scales.

Another is that there are simpler and easier ways to cheat if a merchant is so inclined. Few buyers watch the scales, and even fewer check the price computation. Several surveys have shown that it is

easy for a clerk to ring up nonexistent items without being caught at it.

What about prepackaged items? Again there is no definite, conclusive answer which holds true everywhere. It depends on what you're buying and where you live.

There is no doubt that commercial packaging has reduced the frequency of short-weight selling. When every item was weighed to order, control was difficult, for an inspector couldn't be present to watch every transaction. But with standard packages on the shelves of every market, the inspector's task is easier. To check the weight of a well-known brand, he need only take a few packages from a shelf occasionally, wherever he happens to be. The packer knows that the packages he puts up are available anywhere. If someone finds a few short, the discovery may touch off a whole chain of tests.

Even so, short weight in nationally branded items is not unknown. The West Virginia department, one of the few to name names in its annual report, has a chamber of horrors, where confiscated short-weight packages are on display; and the collection includes some of the best-known brands of coffee, soaps, meat products, beans, motor oil, flour, baking powder, spices, and canned vegetables.

The frequency of short weight can't be estimated. West Virginia condemned one percent of the packages weighed in 1954, and in some other states the proportion ran as high as five percent. But enforcement officials concentrate their efforts on products which they have reason to suspect.

How much of this is accidental? Some of it, no doubt. But where inspectors keep a close record of both overweight and underweight packages, the proportion runs about two to one against the consumer.

One can only guess at the motives underlying short weight in packaged goods, but it's reasonable to assume that a frequent cause is "motivated carelessness." All machines operate with some margin of error. The man who sets the machine to deliver a pound into each package knows this, knows that it will make some packages light, some heavy, though in a good machine no error should exceed a quarter-ounce. If he wants to make a good showing for his department, he is likely to set the machine a trifle low. Ideally—from his point of view—the machine will turn out packages which *average* less than a pound,

but with no *single* package below the legal tolerance. But if the machine is not as precise as he thinks, or if he turns the adjustment screw too enthusiastically, some packages may be confiscated in a grocery store two weeks later.

Of course if no one complains, if no packages are confiscated, he concludes that he's doing all right—or perhaps he hasn't gone quite far enough. So it isn't surprising that this kind of thing happens most often in states where inspection is lax. Packers who operate regionally rather than nationally are well aware of the scrutiny to which their goods will—or will not—be subjected.

What happens to condemned, short-weight packages? Usually only samples are confiscated; the rest are shipped back to the packer. It is not unheard of for a rejected shipment to be promptly re-shipped into a state where there are no inspectors to make a fuss!

If you live in a state where inspection is reasonably good, your chances of getting a short-weight package are probably less than one per hundred. If your state has no inspection—well, of course there are no statistics for such states, because nobody gathers them, but it's certain that your chances are worse.

In Virginia, in 1954, the state department of weights and measures began receiving complaints from residents of a city where there had been no local inspector for several years. State inspectors moved in. Checking twelve markets mentioned in the complaints, they weighed 2,281 packages. Half of them were short weight.

The inspectors knew where to go, and they knew what to weigh. In Virginia as in most other states, the chief trouble-spot is the self-service refrigerated counter, and the worst offender is meat. The chief of the New Jersey service, Joseph Rogers, says flatly, "Short weight conditions are more prevalent in the sale of meat than ever before."

Pound for pound, meat is the most expensive food consumers buy. Once it was cut and weighed in the customer's presence. Now, in many markets, it is prepackaged: cut, wrapped, weighed and price-marked in the back room. Packages of flour, sugar, rice, and other dry commodities are standard in size. Meat packages are not. Each item is an individual proposition. As a consequence, meat is much more difficult for inspectors to control. A national brand of coffee can be

checked in any store, and what holds true in one is likely to be true elsewhere. But a meat counter is a one-store matter.

For the merchant with questionable ethics, the temptations in selling meat can be irresistible. A single ounce means as much as five cents at the cash register. The chances of punishment are small. When a merchant is thus inclined, even the best inspection service will have difficulty putting him down.

If he is crafty as well as greedy, it isn't easy for an inspector to put the finger on him, and it's even harder to prove in court that his offense wasn't a mere accident. Even if he is caught red-handed and convicted, a $50 fine isn't enough to discourage him; he can make that up in a couple of days.

But the significant point is that short weight is only one of the devices such a merchant can use. Quantity is only one measure of a transaction. Price and quality are no less important. If he does his cheating at the cash register, "accidentally" misreading prices or ringing up extra items, apologizing profusely if anyone notices the "mistake," there isn't much inspectors can do about it unless the service employs undercover shoppers who can build up evidence that such "errors" are part of a systematic pattern.

It isn't illegal to leave a little more fat on the roast, for the customer can see what she's getting; and to package meat with the best side up, or to put the best berries on the top layer of the box, is simply good merchandising. In short, an inspection service is invaluable, in that it provides a solid foundation of standards. But no inspection is effective enough to give buyers freedom to be careless. Careless buying is an invitation to fraud, and it penalizes the honest merchant. Fines don't discourage the cheater; what really hurts is when customers decide to buy elsewhere.

What happens at the grocery is, today, only a small part of the whole picture of weight and measure. Today the consumer buys more kinds of things, in more kinds of ways, by more kinds of measurements, than a hundred years ago.

Gasoline, for example. A good weights and measures inspection service tests gasoline pumps, which isn't quite as simple as placing test weights in the pan of a scale. To test a gasoline pump properly, the inspector must check how accurately it meters the flow of gasoline

not merely when the storage tank is full, but also when it is nearly empty.

Fuel oil is delivered to the home through a metering pump, one the customer seldom sees, and he has no way of measuring accurately how much has been added to his tank. The sale of coal has always been difficult to police. Perhaps the trickiest problem of fuel measurement is bottle gas, and some states still have not amended their laws to regulate the sale of this item.

Each of these problems calls for special equipment, some of it bulky and expensive, training inspectors in how to use it, and calibrating it. The National Bureau of Standards, of course, provides the standards—not merely the units of measurement, but standards for the performance of and use of special-purpose measuring equipment.

Usually a weights and measures department limits its work to questions of quantity, but a few also consider quality. The Los Angeles County department is notable for its petroleum laboratory. When gasoline pumps are checked for accuracy, samples of the fuel are taken for analysis. Occasionally they find that low-quality bootleg gasoline is being sold under a well-known premium brand name.

But by no means all of what a local weights and measures office does is enforcement. Indeed, members of the profession prefer the word "administration." Catching the cheater is a nuisance, however necessary; a diversion of time and energy from the not inconsiderable task of keeping all kinds of measuring devices up to standard.

Your druggist may be a completely honest man, without the slightest desire to scant in making up a prescription. But he can be just as wrong as the scoundrel if his measuring instruments are in error, with consequences just as unhappy; and he can't be sure they're accurate unless there is a weights and measures organization to verify them occasionally.

Surveyors' tapes sold by reputable manufacturers are accurate when new, but they can change with use. The surveyor may be skillful, but his surveys can cause no end of trouble to titleholders if his tape isn't right. He can't send it to Washington for periodic checking; the National Bureau of Standards can't handle such a volume of business. He depends on whatever weights and measures service his state provides.

State highway departments call on the service to check their truck-weighing scales. Modern dairy farmers don't deliver their milk in cans; it's held in farm tanks until the dairy's tank truck arrives. The tank must be calibrated if the farmer is to know how much milk he's selling.

Some states require, by law, that a new type of weighing machine be approved before it's sold or used. The weights and measures inspectors make the engineering studies. They may also examine and certify the weighmasters, whose bonded services are called for in some commercial contracts. In some states scale mechanics and repairmen are also licensed.

In fact, if you simply keep your eyes open, where you shop, where you work, wherever you happen to be, you may be surprised to realize how much measurement is used to control the processes of ordinary affairs. It isn't all buying and selling, either. Industry uses thousands of weighing devices in processing operations. Some of your physician's diagnostic procedures involve measurement.

Ordinary weighing instruments are verified rather easily. But when they come in out-sizes, testing can be complicated. In one conspicuous case the National Bureau of Standards doesn't ask that instruments be sent to its laboratories for testing. Rail travelers occasionally see a cobalt-blue car with the Bureau's name painted in gold letters. It travels the nation's rail lines, testing the scales used to weigh loaded freight cars. The largest commercial scale, incidentally, has a capacity of ten million pounds. Even an ingenious local inspector would be hard put to it to certify that one!

So there is plenty for a local inspection service to do, much routine work, some detective work, and from time to time a special job that taxes the technical facilities and skills of the department. A factory, for example, may call for help in calibrating a large industrial tank.

Of the forty-odd state governors who sent messages to their legislatures in 1955, only two mentioned weights and measures. It isn't a priority item today. Yet the annual reports of state and municipal departments are neither smug nor altogether reassuring.

Most of them say what Grein and Derry said: They are understaffed, under-financed and not sufficiently well-equipped. One of the largest and wealthiest counties of an eastern state has a single inspector

to do everything that has to be done. What happens in the grocery in that county lies between the grocer and the consumer; there isn't much one inspector can do. Some large cities have doubled in population without increasing their inspection staffs. Some departments can't begin inspecting certain kinds of devices for lack of heavy equipment.

But, under our laws, this is a local matter. It's up to the citizens of any state or city to decide how much enforcement they want and how much they'll pay for. Because this is the law, no one can answer, in detail, the basic question: What's going on? The states with the best inspection services have the most detailed records. But for many states there simply isn't any information. One can reason and generalize, but there are no figures which show how often a consumer gets short weight and short measure.

But there has been a change, a tremendous change since the days of Athelstan's barleycorn standards, since Henry VII's octagonal yard bar, since Hassler first surveyed conditions in the United States, and since the National Bureau of Standards made its survey in the early 1900s. In our time, and for the first time in the world's history, the standards of weight and measure have become fixed, universal, and available to all.

Individual merchants here and there may cheat and chisel, but they cannot corrupt the system. Their potential excesses are held in check by the knowledge that error can no longer be held out as truth, that they operate within a framework so secure that no man can challenge it before a court. A false weight may be false by design or by accident; but if it is ever subjected to testing it will, inevitably and conclusively, be exposed as false.

John Quincy Adams defined the qualities of an ideal system: uniformity, permanency, universality, one standard to be the same for all persons and places. But these purposes, he declared, required powers which no legislator had hitherto been found to possess.

No legislator has yet been found to possess such powers, but the purposes have been largely achieved without them. Congress has never yet fully exercised its Constitutional powers, as early Presidents urged it to do. Our national standards are not supported by a code of law and penalties.

But with a minimum of law and a minimum of enforcement,

Adams' goals have been largely achieved. Though legislatures of nations still uphold such anachronisms as the British Imperial Yard and Pound, scientists speak the same language everywhere. The international meter and kilogram have the same meaning here as they do in London, Rome, and Moscow. On these standards and the universal standard of time, and on the physical constants which are the foundations of research and engineering, there has been built a firm, permanent structure of standards, standards to measure atoms and galaxies, a bond between all men who seek knowledge.

ABOUT THE AUTHOR

A "RESIDENT" OF ALMOST "EVERYWHERE" IN THE UNITED STATES, John Perry makes his permanent home in Washington, D. C., with his family, Jane Greverus Perry and their daughters Forest and Gale, and a son Jefferson.

Mr. Perry was born in Newark, New Jersey, and was schooled at Tabor and Montclair Academies and at Lehigh University. After college he was employed as a market researcher, a public relations counsellor, and government specialist. For the last ten years or more, he has had his own business as a management consultant, and as well has written many articles for *Nation's Business, Public Opinion Quarterly, Harvard Business Review,* and other journals in the business field. Continuing his interest in science matters he was, in 1946-47, also the editor of *Federal Science Progress.*

Besides his writing, including two recent books, *Human Relations in Small Industry* and *Our Wonderful Eyes,* as well as the present work, Mr. Perry is, in vacation and spare time, an enthusiastic follower of the outdoor life, enjoying camping and water sports with his family.

The rise and decline of the ferryboat on the American scene is the subject of the author's next book and it promises to be an important item in the ever widening field of interest in Americana.

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